

**A Conceptual Framework for Technology Roadmapping:  
An Electricity Utility Perspective**

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Academic Supervisor: Dr Ronel Blom PhD

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# DECLARATION

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Gregory Robert Tosen

12 June 2023

## ACKNOWLEDGEMENTS

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## ABSTRACT

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This study sought to provide new insights on issues related to the technology roadmapping processes, design, and practice within electricity utilities. The study was designed to develop an improved theoretical contribution to current roadmapping methods and aims to enhance the practices and approaches of the earlier generation technology roadmaps. A mixed method abductive approach was applied to the research study and is based on a pragmatism paradigm. The study population and sample comprised experienced research and development participants from the global electricity sector. Qualitative focus group workshops and quantitative surveys were carried out with the participants regarding their responses to an ever-changing ecosystem where the rate of technological adaptation and changes outpace business processes.

A key finding from the analysis was that under COVID-19 conditions, technology resilience was seen as the most critical element in defining future technology applications and, thus, technology roadmapping methodologies. Other findings indicated the lack of a systemic perspective, ecosystem understanding, and a general perception that short-term technology requirements dominate current technology roadmapping thinking and practices.

The study developed a conceptual technology roadmap framework that would create significant value for the long-term technology sustainability of electricity utilities. This is especially critical with respect to the processes of technology applications, strategic technology planning, risks, and implementation. The unique characteristic is that the conceptual technology roadmapping framework is multi-functional both in the vertical and horizontal planes and interacts in a non-linear manner and where technology resilience is considered a critical building block in the decision-making process. Thus, the roadmapping framework could lay a solid foundation for organisations for an alternative, more robust, systemic, and resilient approach to technology roadmapping.

Key Words: Technology roadmapping, systemic, resilience, sustainability, ecosystem

# TABLE OF CONTENTS

DA VINCI COPYRIGHT INFORMATION.....	II
DECLARATION.....	III
ACKNOWLEDGEMENTS .....	IV
ABSTRACT.....	V
LIST OF FIGURES .....	X
LIST OF TABLES.....	XIII
LIST OF APPENDICES.....	XIV
ACRONYMS.....	XV
CHAPTER 1.....	1
INTRODUCTION.....	1
1.1 Background.....	1
1.2 Research context.....	5
1.3 Research philosophy .....	8
1.3.1 <i>Ontological perspective</i> .....	8
1.3.2 <i>Epistemological perspective</i> .....	9
1.3.3 <i>The researcher's axiology</i> .....	11
1.4 Research problem .....	12
1.5 Research aim and objectives .....	13
1.5.1 <i>Aim</i> .....	13
1.5.2 <i>Objectives</i> .....	14
1.6 Research questions.....	14
1.7 Research design.....	16
1.8 Ethical considerations.....	18
1.9 Scope and limitations of the study.....	18
1.10 Structure of the thesis.....	19
1.11 Conclusion .....	21
CHAPTER 2.....	22
LITERATURE REVIEW.....	22
2.1 Introduction .....	22
2.2 The history of technology roadmapping.....	24
2.3 Roadmapping definitions .....	25

2.4	Trends in technology roadmapping .....	31
2.4.1	<i>First generation technology roadmaps</i> .....	31
2.4.2	<i>Second generation technology roadmaps</i> .....	33
2.4.3	<i>Third generation technology roadmaps</i> .....	33
2.5	Technology management .....	35
2.5.1	<i>The role of transition management theory in technology roadmapping</i> .....	38
2.5.2	<i>Technology roadmapping formats and levels</i> .....	41
2.6	Roadmapping approaches .....	47
2.6.1	<i>Expert-based approach</i> .....	48
2.6.2	<i>Computer-based approach</i> .....	51
2.6.3	<i>Hybrid approach</i> .....	52
2.7	Technology roadmapping in the electricity and energy sector .....	54
2.7.1	<i>National technology roadmaps</i> .....	56
2.7.2	<i>Industry and sector technology roadmaps</i> .....	57
2.7.3	<i>Organisational roadmaps</i> .....	59
2.8	Gaps and conclusion .....	60
<b>CHAPTER 3.....</b>		<b>64</b>
<b>CONCEPTUAL FRAMEWORK FOR AN ALTERNATIVE SYSTEMIC TECHNOLOGY ROADMAP .....</b>		<b>64</b>
3.1	Introduction .....	64
3.2	Theoretical grounding for the systemic technology roadmapping framework .....	66
3.2.1	<i>The multi-dimensional perspective of complex systems</i> .....	67
3.3	Proposed conceptual technology roadmap .....	72
3.4	Proposed roadmapping format and process .....	73
3.4.1	<i>Preliminary activities</i> .....	75
3.4.2	<i>Phase 1 - Current reality systems perspective</i> .....	76
3.4.3	<i>Phase 2 – Short-term systems perspective</i> .....	77
3.4.4	<i>Phase 3 – Medium-term systems perspective</i> .....	78
3.4.5	<i>Phase 4 – Long-term systems perspective and systems integration</i> .....	79
3.5	Conclusion .....	79
<b>CHAPTER 4.....</b>		<b>81</b>
<b>RESEARCH DESIGN AND METHODOLOGY .....</b>		<b>81</b>
4.1	Introduction .....	81
4.2	Research design .....	81
4.2.1	<i>Research philosophy and approach</i> .....	82
4.2.2	<i>Research methodology</i> .....	83
4.3	Population and sampling .....	84
4.3.1	<i>Data collection and analysis</i> .....	86
4.3.2	<i>Quantitative collection and analysis</i> .....	94
4.4	Data integrity .....	97

4.4.1	<i>Trustworthiness</i> .....	98
4.4.2	<i>Credibility</i> .....	100
4.4.3	<i>Transferability</i> .....	102
4.4.4	<i>Dependability</i> .....	102
4.4.5	<i>Confirmability</i> .....	102
4.5	Delimitation of the study .....	103
4.6	Ethics .....	103
4.7	Conclusion .....	104
<b>CHAPTER 5.....</b>		<b>105</b>
<b>BRUSSELS, BERLIN AND SURVEY DATA ANALYSIS .....</b>		<b>105</b>
5.1	Introduction .....	105
5.2	Background to the Brussels and Berlin focus group workshops .....	107
5.3	Introductory quantitative survey .....	109
5.3.1	<i>Brussels analysis</i> .....	109
5.3.2	<i>Berlin quantitative analysis</i> .....	113
5.4	Focus group workshop .....	119
5.4.1	<i>Brussels focus group workshop</i> .....	121
5.4.2	<i>Berlin focus group workshop</i> .....	142
5.4.3	<i>Brussels and Berlin focus group comparative analysis</i> .....	159
5.4.4	<i>Qualitative survey 2021</i> .....	164
5.4.5	<i>Critical constructs</i> .....	174
5.5	Conclusion .....	178
<b>CHAPTER 6.....</b>		<b>181</b>
<b>RESEARCH RESULTS AND FINDINGS .....</b>		<b>181</b>
6.1	Introduction .....	181
6.2	Integration of qualitative datasets.....	181
6.2.1	<i>Absorptive capacity</i> .....	188
6.2.2	<i>Critical elements</i> .....	191
6.2.3	<i>Business process obstacles</i> .....	194
6.2.4	<i>Critical constructs</i> .....	198
6.3	Conclusion .....	200
<b>CHAPTER 7.....</b>		<b>205</b>
<b>CONCLUSION.....</b>		<b>205</b>
7.1	Introduction .....	205
7.2	Summary of findings .....	206
7.3	Proposed conceptual technology roadmapping framework.....	209
7.3.1	<i>Preliminary phase</i> .....	211
7.3.2	<i>Phase 1 - Current reality systems perspective</i> .....	212
7.3.3	<i>Phase 2 - Short-term systems perspective</i> .....	214

7.3.4	<i>Phase 3 - Medium-term systems perspective</i> .....	216
7.3.5	<i>Phase 4 - Long-term systems perspective and systems integration</i> .....	217
7.4	Contribution of the study.....	218
7.5	Return on investment .....	220
7.5.1	<i>Personal ROI</i> .....	220
7.5.2	<i>Organisational ROI</i> .....	221
7.5.3	<i>Societal ROI</i> .....	221
7.6	Limitations of the study.....	221
7.7	Recommendations for further research.....	223
7.8	Conclusion .....	223
	<b>REFERENCES</b> .....	<b>225</b>
	<b>APPENDICES</b> .....	<b>253</b>

# LIST OF FIGURES

---

Figure 1.1:	Martec's Law .....	2
Figure 1.2:	A knowledge-based perspective of the future.....	4
Figure 1.3:	Change, complexities and competition in industries .....	5
Figure 1.4:	Parallel mixed method design .....	11
Figure 1.5:	Thesis framework .....	20
Figure 2.1:	Literature review map .....	24
Figure 2.2:	T-Plan fast-start technology roadmapping process .....	29
Figure 2.3:	The STAR methodology framework.....	30
Figure 2.4:	Schematic example of a first generation roadmap.....	32
Figure 2.5:	Characterisation of technology roadmaps, purpose and format .....	37
Figure 2.6:	Framework for technology roadmapping .....	38
Figure 2.7:	Multi-phase and multi-level concepts of transition .....	40
Figure 2.8:	Generic roadmapping framework showing nodes and links .....	44
Figure 2.9:	A hypothetical technology roadmap.....	45
Figure 2.10:	Roadmapping taxonomy.....	46
Figure 2.11:	Inside-out perspective (a) and outside-in perspective (b) .....	53
Figure 2.12:	Breakdown of public domain electricity and energy roadmaps .....	54
Figure 2.13:	IEA technology roadmapping process .....	57
Figure 2.14:	Strategic roadmap for Industry 4.0 implementation .....	59
Figure 3.1:	Interactive planning .....	70
Figure 3.2:	Tools for the system thinker .....	70
Figure 3.3:	Core elements of the TIPS™ Managerial Leadership Framework.....	71
Figure 3.4:	A conceptual technology roadmap .....	73
Figure 3.5:	Proposed conceptual technology roadmapping format and process .....	75
Figure 3.6:	Backcasting approach .....	76
Figure 4.1:	The potential global respondents .....	85
Figure 4.2:	Data collection process map .....	87
Figure 4.3:	Process of workshop engagement .....	89
Figure 4.4:	Industry membership affiliations .....	90
Figure 4.5:	Membership by region and category .....	95
Figure 4.6:	Parallel mixed method design .....	99
Figure 5.1:	Thematic analysis for analysing qualitative data for this study .....	106
Figure 5.2:	Example of textual coding and analysis on QDA Lite .....	107
Figure 5.3:	Experience of Brussels focus group members involved in TRM activities .....	110
Figure 5.4:	Number of years Brussels focus group members involved in TRM activities .....	110
Figure 5.5:	What was the planning horizon in years of your organisation TRM? .....	111

Figure 5.6:	What was the primary motivation for undertaking the TRM? .....	111
Figure 5.7:	Based on the above question, what are the likely impacts of the technological outcomes? .....	112
Figure 5.8:	What were the main factors that influenced the TRM outcomes (1=least important and 5=most important).....	113
Figure 5.9:	Experience of members involved in TRM activities .....	113
Figure 5.10:	Number of years members involved in TRM activities.....	114
Figure 5.11:	Number of years the Brussels and Berlin members involved in TRM activities .....	114
Figure 5.12:	What was the planning horizon in years for your organisation's TRM? .....	115
Figure 5.13:	What was the primary motivation for undertaking the TRM exercise? .....	115
Figure 5.14:	What was the primary motivation for undertaking the TRM exercise? .....	116
Figure 5.15:	Based on the above questions what is the likely impact of these technological outcomes? .....	117
Figure 5.16:	Based on the above questions what is the likely impact of these technological outcomes? .....	118
Figure 5.17:	What were the main positive factors that influenced the TRM outcomes? .....	118
Figure 5.18:	Frequency of coded words for the category 'absorptive capacity' .....	125
Figure 5.19:	Frequency of coded words for the category 'critical elements of a TRM framework' .....	130
Figure 5.20:	Frequency of coded words for the category 'organisational process obstacles' .....	138
Figure 5.21:	Frequency of coded words for the category 'critical constructs'.....	141
Figure 5.22:	The frequency of coded words for the category 'absorptive capacity' .....	145
Figure 5.23:	The frequency of coded words for the category 'critical elements of a TRM framework' .....	148
Figure 5.24:	The frequency of coded words for the category 'organisational process obstacles' .....	151
Figure 5.25:	The frequency of coded words for the category 'critical constructs'.....	155
Figure 5.26:	Frequency of codes from the Brussels and Berlin workshops .....	163
Figure 5.27:	Word cloud of codes for the Brussels and Berlin workshops.....	164
Figure 5.28:	The frequency of coded words for the category 'absorptive capacity' .....	168
Figure 5.29:	The frequency of coded words for the category 'critical elements of a TRM framework' .....	169
Figure 5.30:	The frequency of coded words for the category 'organisational process obstacles' .....	174
Figure 5.31:	The frequency of coded words for the category 'critical constructs' .....	175
Figure 5.32:	Frequency of codes for the survey dataset.....	178
Figure 6.1	Frequency of codes for Brussels, Berlin, and survey datasets .....	183
Figure 6.2:	Word cloud and tree map of codes for the Brussels, Berlin and survey datasets...	184
Figure 6.3:	Trajectory analysis for codes ecosystem understanding, operational perspective and resilience .....	186
Figure 6.4:	The cumulative frequency of all codes for all categories for the Brussels, Berlin and survey datasets .....	187

Figure 6.5:	The frequency of selected codes from the three datasets .....	187
Figure 6.6:	The total frequency of codes for the category absorptive capacity for the Brussels, Berlin and survey datasets .....	189
Figure 6.7:	The frequency of codes for the category absorptive capacity.....	191
Figure 6.8:	The total frequency of codes for the category 'critical elements' for the Brussels, Berlin, and survey datasets .....	192
Figure 6.9:	The frequency of codes for category 'critical elements' for the Brussels, Berlin, and survey questionnaire datasets .....	194
Figure 6.10:	The total frequency of codes for the category 'business process obstacles' for the Brussels, Berlin and survey datasets.....	195
Figure 6.11:	The frequency of codes for the category business process obstacles for the Brussels, Berlin, and survey datasets.....	196
Figure 6.12:	The total frequency of codes for the category 'critical constructs' for the Brussels, Berlin, and survey datasets .....	199
Figure 6.13:	The frequency of codes for the category 'critical constructs' for Brussels, Berlin, and survey datasets .....	200
Figure 6.14:	Critical success factors and barriers to success to consider in the technology roadmapping approach.....	203
Figure 7.1:	Proposed conceptual roadmapping framework .....	210

## LIST OF TABLES

---

Table 1.1:	Research questions (RQ) .....	15
Table 2.1:	Analysis of approaches and tools used in technology roadmaps .....	55
Table 4.1:	Sector members at the Brussels workshop .....	91
Table 4.2:	Sector members at the Berlin workshop .....	91
Table 4.3:	Data collection and analysis .....	91
Table 4.4:	An abridged example of survey questions .....	92
Table 4.5:	Example of QDA Miner coding and categories. ....	94
Table 4.6:	Example of compulsory questions .....	96
Table 4.7:	Data analysis .....	96
Table 5.1:	Member participants attending the Brussels focus group workshop .....	108
Table 5.2:	Member participants attending the Berlin focus group workshop .....	109
Table 5.3:	Brussels focus group themes, categories, and codes .....	121
Table 5.4:	Berlin focus group themes, categories and codes.....	143
Table 5.5:	Themes, categories and codes .....	166
Table 5.6:	Number of responses by country and region .....	166
Table 7.1:	Summary of objectives, research questions and the key propositions .....	206

# LIST OF APPENDICES

---

Appendix 1:	Solicitation letter .....	253
Appendix 2:	Introductory quantitative survey questions for Brussels and Berlin focus group participants .....	254
Appendix 3:	Quantitative survey results for the Brussels focus group participants.....	258
Appendix 4:	Quantitative survey results for the Berlin focus group participants .....	263
Appendix 5:	Brussels and Berlin focus group open-ended questions.....	268
Appendix 6:	Brussels focus group responses.....	270
Appendix 7:	Qualitative table of categories, codes and frequencies for the Brussels workshop	281
Appendix 8:	Berlin focus group responses .....	282
Appendix 9:	Qualitative table of categories, codes and frequencies for the Berlin workshop .....	292
Appendix 10:	Survey questionnaire feedback .....	293
Appendix 11:	Qualitative table of categories, codes and frequencies for survey 2020/21 .....	329

## ACRONYMS

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<b>AI</b>	Artificial Intelligence
<b>CCGT</b>	Combined Cycle Generating Technology
<b>CEO</b>	Chief Executive Officer
<b>COP</b>	Conference of Parties
<b>CSF</b>	Critical Success Factors
<b>DMAIC</b>	Defining, Measuring, Analysing, Improving and Controlling
<b>DMEODVI</b>	Defining, Measuring, Evaluating, Optimizing, Developing, Validating and Implementing
<b>DFSS</b>	Design For Six Sigma
<b>EMS</b>	Environmental Management Systems
<b>IEA</b>	International Energy Agency
<b>IoT</b>	Internet of Things
<b>IRO</b>	International Research Organisation
<b>JV's</b>	Joint Ventures
<b>KPI</b>	Key Performance Indicators
<b>NGO</b>	Non-Governmental Organisation
<b>PESTLE</b>	Political, Economic, Social, Technological, Legal and Environmental
<b>PLS</b>	Partial Least Squares
<b>QDA</b>	Qualitative Data Analysis

<b>QFD</b>	Quality Function Deployment
<b>R&amp;D</b>	Research and Development
<b>ROI</b>	Return on Investment
<b>RQ</b>	Research Question
<b>SEM</b>	Structural Equation Modelling
<b>STAR</b>	Strategic Technology Alignment Roadmap
<b>SWOT</b>	Strengths, Weaknesses, Opportunity and Threats
<b>TIPS</b>	Technology, Innovation, People and Systems
<b>TMT</b>	Transition Management Theory
<b>TRM</b>	Technology Roadmap
<b>UNESCO</b>	United Nations Educational, Scientific and Cultural Organisation

# CHAPTER 1

## INTRODUCTION

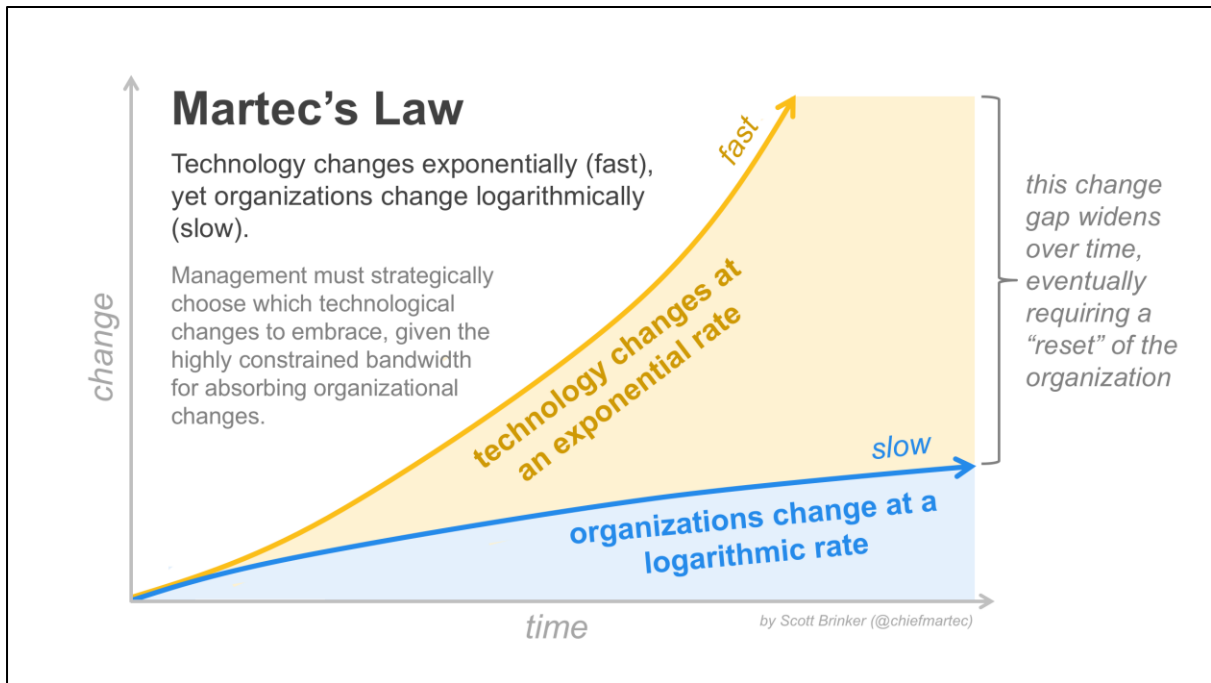
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### 1.1 Background

Firms today are required to be more receptive to technological change and to manage their technology assets more strategically. However, organisational dissemination of technology strategy and planning has unwittingly shifted the bulk of technology decisions to people within an organisation. Generally, these people are unfamiliar with the rate and dynamics of technology in the marketplace, resulting in poor technology integration within organisations.

An important aspect to consider based on Moore's (2016:70) work is that technology undergoes transformations at an exponential rate, known as Moore's Law – also referred to as Kurzweil's Law of Accelerating Returns (Kurzweil, 2005:65). However, the work of Brinker (2016:12) has shown that organisations change at a logarithmic rate, which is considerably slower than that of technology, which changes at an exponential rate.

Brinker's (2016:12) study proposes a law which captures organisations' greatest challenge of the decade: how to manage comparatively slow and reactive changing organisations in a fast-changing technological world. This law, known as Martec's Law (Brinker and McLellan, 2020:4), is shown graphically in Figure 1.1.



**Figure 1.1: Martec's Law**

Source: Brinker and McLellan (2020:4)

The solution, according to some, is a systematic approach in the business to integrated technology planning called Technology Roadmapping (Garcia, 1998:20; Phaal *et al.*, 2016:12). However, the current application of Technology Roadmapping is isolated in its approach and is dominated by linear thinking (Kamtsiou, 2016:106). This further exacerbates systematic vagueness, as well as serving to oppress creativity, communication, collaboration, and integration in the science and technology planning domain. Thus, linear thinking in the technology roadmapping process could have unintended consequences for organisations from a technology strategy perspective.

Generally speaking, a 'roadmap' is a route that exists in some specific geographic space. Thus a roadmap serves as a traveller's tool that provides essential understanding, proximity, course, and some degree of certainty, in travel planning.

The preparation of technology roadmapping comprises several processes, including social mechanisms, and is considered both a learning experience and an interactional

tool for the participants and organisations. In his seminal work, Galvin (1998: 803), the former Chairman of Motorola, defines a roadmap as,

*...an extended look at the future of a chosen field of inquiry composed from a collective knowledge and imagination of the brightest drivers of change in that field.*

Galvin (1998) further states,

*In engineering, the roadmapping process has so positively influenced public and industry officials that their questioning of support for fundamental technology support is muted.*

Phaal, Farrukh and Probert (2013:374) define their interpretation of a roadmap as,

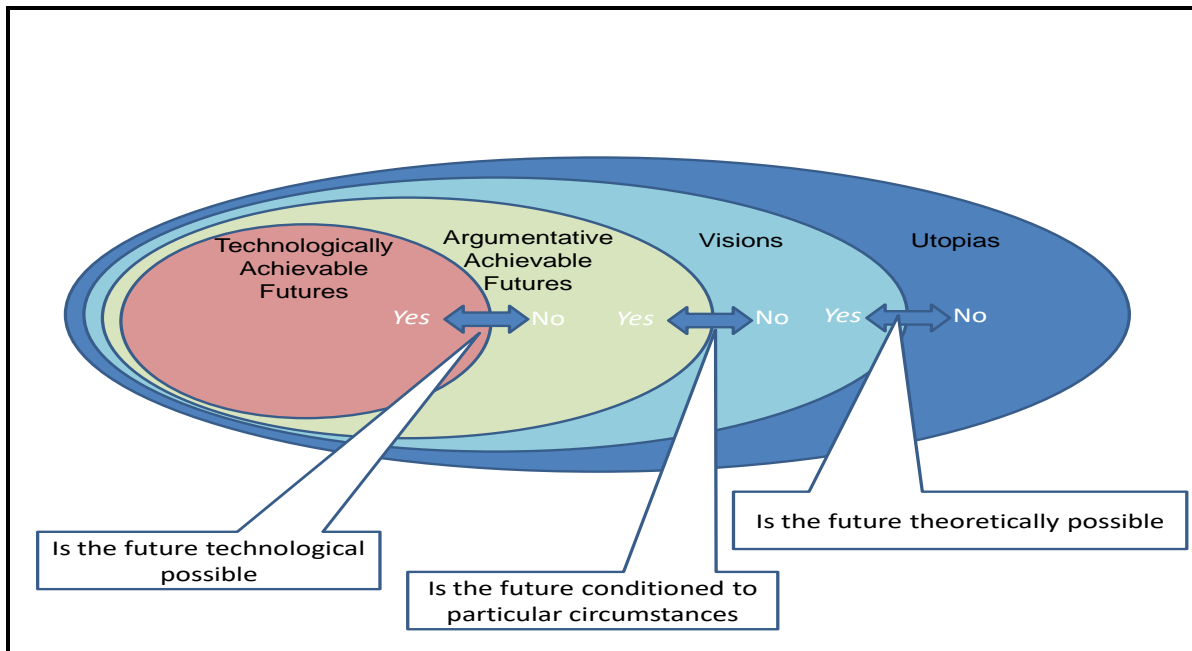
*A linchpin management tool that can help support integration with other needed strategic and operational management processes, it does not stand alone and the bottom line, it is roadmapping that delivers results; the focus cannot just be on the roadmaps.*

Thus a technology roadmap provides a consensus view or vision of the future technology landscape available to decision makers (Radnor and Probert, 2004:32; Phaal *et al.*, 2013:17).

Addressing the purpose and benefit of roadmaps, Galvin (1998:803) further states, 'roadmaps communicate visions, attract resources from business and governments, stimulate investigations, and monitor progress.' Thus, roadmaps are considered an essential component of a broader industrial innovation preparation approach regarding sustainability and competitiveness.

Tosen (2004:45) defines the roadmapping process as a way to identify, evaluate, and select strategic alternatives that can be applied to achieve the desired technology objective based on an organisation's possible future vision, as depicted in Figure 1.2. The figure highlights the iterative process of defining and searching for plausible

futures and deliberating whether the futures defined are theoretically conceivable and likely. In addition, critical to the process is to constantly question the technological feasibility of the system as one moves from one phase to the next.

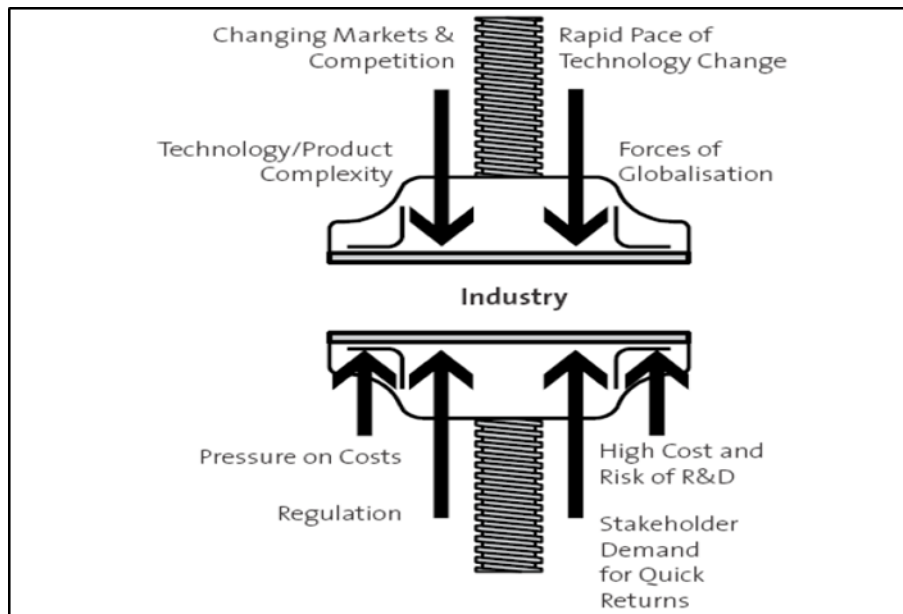


**Figure 1.2: A knowledge-based perspective of the future**

*Source: Tosen (2004:8)*

The following graphic, Figure 1.3, depicts those critical external and internal pressures and stresses that impact organisational competitiveness from a global economic perspective. The factors of geopolitical forces, technology complexity, shifting customer and stakeholder demands, environmental risk and sustainability, and the constant pressure of shareholder demands are vital considerations that organisations need to consider.

Thus, as an imperative, technology leaders must continually focus on these issues to ensure organisational competitiveness and long-term sustainability.



**Figure 1.3: Change, complexities and competition in industries**

*Source: Du Preez and Louw (2007:5)*

A key component in this approach is developing a sound and robust technology roadmapping methodology which inculcates the concept of holistic systems thinking. Holistic systems thinking reflects the ability to consider the interconnections and relationships of the various components in the environment in all decision making processes. Thus, when considering a systems approach, we consider the system as a whole, which consists of a number of interdependent parts or elements (Ackoff, 1970:8; Senge, 2000:327; Hossain, Ullah, Raed, Hamilton, Keating and Goerger, 2020:27). What is vital in the understanding of systems thinking, is the understanding of the arrangement of the parts within a system and the way the parts interact with each other and with its environment. Thus, the ability to understand the complexity of a system is central to any decision making process (Senge, 2000:327; Churchman, 1968:45; Gharajedagh, 2014:85; Hossain, et al., 2020:27).

## 1.2 Research context

Technology is a crucial resource of profound importance to corporate profitability and growth and is a prime determinant of a country's wealth and development.

Technological development is a pervasive process that has shaped the 21st century in several ways. Its impact on society is such that it can be considered the prime driving force in the contextual environment of business, not only because of its direct impact but also because of its indirect impact.

The word 'technology' is often used as a synonym for a 'technology artefact'. This is, however, an incomplete and simplistic view. Definitions of technology abound in the literature. Van Wyk (2017:14) gives a satisfactory definition which, slightly amended, states that 'technology is the systematic application of knowledge to resources to produce goods or services'.

Evidence shows that there is only a small step between the national and the corporate culture in the successful exploitation of technology and the changes brought about by technological innovation. The work of Pistorius (2000:25) indicates a link between a positive technological orientation in the mindset of top management, and he assumes that it is a prerequisite for the cultivation of an organisational technology-positive culture. Pistorius (2000:35) states that technological literacy and a progressive national attitude to innovation are key drivers in ensuring organisational, national, and global competitiveness. In his paper, Pistorius (2000:39) shows evidence between an organisational corporate culture pertaining to technology development and a country's competitiveness.

Others agree that nations that can rapidly improve their productivity and over time, will improve their wealth (Maksimovis, Demirgüç-Kunt and Ayyagari 2016:400; Yoon, Anderson, Lin and Elinich, 2017:425). Conversely, nations eroding their positions or losing their wealth do not keep up productivity growth as fast as their competitors do (Fedderke and Romm, 2006:738; Schwab, 2016:22).

The Global Competitiveness Report (Schwab, 2019:110) discusses and summarises some of the previously mentioned infrastructural indicators for 141 economies. The report indicates that there is a strong correlation between national productivity and the wealth of a nation, which is closely linked to technology adoption (Schwab, 2019:110). While education and innovation play a key role in determining a nation's competitive

potential, the nation's infrastructure (transport, communications, electricity, water and other) also plays a supporting and facilitating role (Schwab, 2019:110).

This poses an interesting question in terms of a country's infrastructure and the ability to have an appropriate and stable electricity supply. Thus, the question could be asked; are electricity utilities located in countries with a higher global competitive index indeed more technologically innovative and strategically astute than those in the lower competitive index countries? It appears that a country's technological skills and capability to innovate are crucial to its global competitiveness and national development. This has led to much urgency for countries to implement far more wide-ranging and enabling policies concerning technology development and implementation in recent years.

It is important to briefly, at this point, consider the purpose of a country's national science and technology (S&T) policy. The United Nations Educational, Scientific and Cultural Organisation (UNESCO, 2015:35) states the purposes as follows,

*'...the development and fruitful use of national scientific and technological resources in order to promote the advancement of knowledge, encourage innovation, increase productivity and thus attain the objectives of the country's economic, social and cultural development more quickly and surely'.*

In their study, Lundvall, Joseph, Chaminade and Vang (2011:45) outline some of the salient trends in national policies for industrial technological change over the last three decades. The 1960s were characterised by largely uncoordinated 'science' policies and 'industrial policies'. These gave way to a more integrated approach to the 'innovation policies' of the 1970s. The 1980s saw a more focused collaborative, pre-competitive research based 'technology policies' approach (Lundvall *et al.*, 2011:45).

In policy development post-2000, the emphasis has been on the technological strengthening of development regions, mainly through the enhancement and creation of technology transfer structures, and on intensifying efforts to assist the endeavours of small and medium enterprises. In 2000, in an attempt to assist planning in

technology, and to a lesser extent in science at the national level, several countries (e.g. United Kingdom, Australia, United States and South Korea) undertook systematic 'technology foresight studies' with a number of developing nations (Lundvall *et al.*, 2011:45; Zamani *et al.*, 2022:65).

The significant involvement of the private electricity sector in formulating and assisting in national technology strategy was noticeable and essential. However, a critical aspect that needs be considered is the inculcation of value promoting technological development and innovation, which is a critical driver for a nation's productivity performance and global competitiveness (Lundvall *et al.*, 2011:45; Yoon *et al.*, 2017:425; EPRI., 2020:53).

## **1.3 Research philosophy**

### *1.3.1 Ontological perspective*

*To a pragmatist, the mandate of science is not to find truth or reality, the existence of which are perpetually in dispute, but to facilitate human problem-solving (Powell and DiMaggio, 1991:235).*

The researcher is a South African and has completed tertiary studies, namely a BSc in Operations Research, a Diploma in Meteorology, an MSc in Atmospheric Modelling, and several executive courses from internationally renowned institutes and universities. His career has spanned 32 years in the electricity sector in South Africa.

The researcher's career began in the scientific field as an atmospheric scientist, where he later developed his experience in many aspects of the electricity business's scientific and engineering technologies. He successfully transformed from a Chief Researcher to an executive position as General Manager Research and Development of an electricity utility in South Africa. He occupied this position for 15 years and worked for the organisation for 32 years before retiring in 2016.

The researcher was fortunate enough to have worked with many major global companies on developing technology research and development strategies and is currently Advising Emeritus Chairman of the International Research Organisation (IRO). This organisation has a membership of 63 of the world's major electricity companies. The researcher is currently at faculty member at the Da Vinci Business School, a Private Higher Education Institute.

Notwithstanding the accomplishments in his profession and with his company, the researcher recognises the current challenges facing global electricity utilities in ensuring sustain performance amongst a number of economic, sociological, and environmental challenges. The researcher has experience and understanding in the area of technology strategy, the management of technology, and in particular, in the area of research and development related to the electricity industry.

As discussed by Saunders, Lewis and Thornhill (2009:87), ontology has to do with the nature of reality, and they maintain that two types of reality exist; i.e. objectivism and subjectivism. According to Creswell (2014:115), objectivism characterises the position that social entities exist in reality outside of the social actors concerned with their existence. Thus, individuals exist within a reality that is outside of them and autonomous of them.

In contrast, subjectivism occurs when social phenomena are created from the perception and consequential actions of those social actors concerned with their existence. Thus, individuals create the world around them through their perceptions and social interactions, which give meaning to reality. The researcher's prior experience has strongly focused on an objectivist stance. Thus, the researcher has adopted a pragmatic paradigm abductive approach.

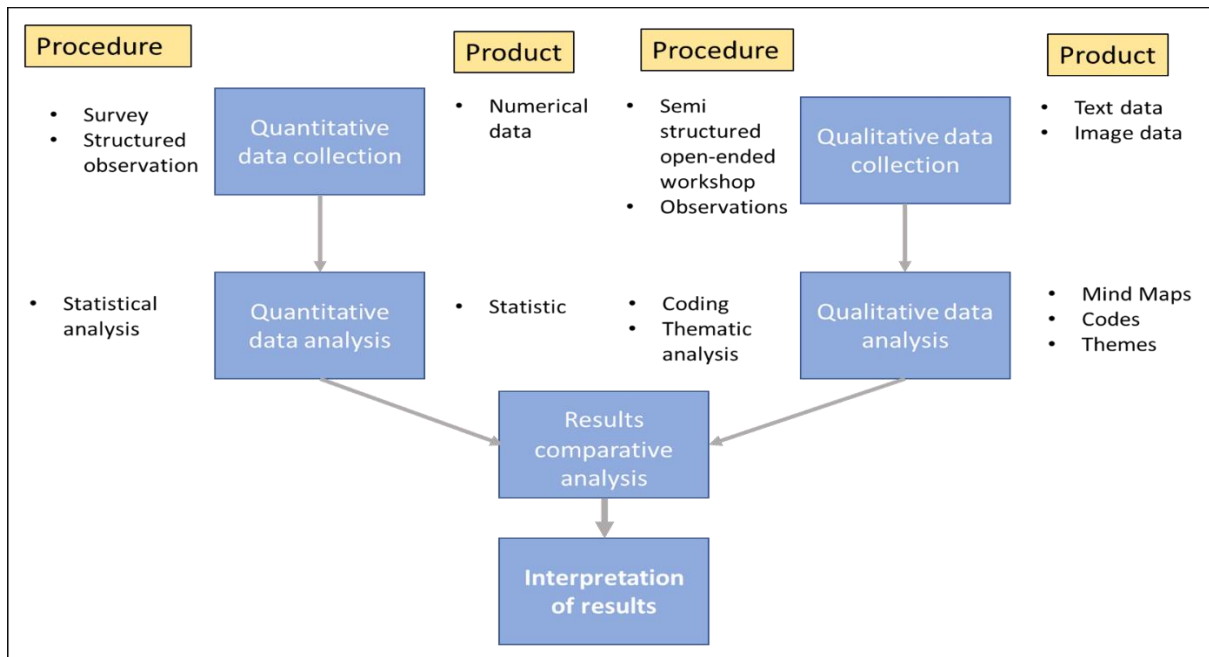
### *1.3.2 Epistemological perspective*

As described by Yin (2011:93) 'epistemology is the philosophical underpinning of the researcher's belief regarding the nature of knowledge and how it is derived or created'. Saunders *et al.* (2009:87) describe interpretivism as the epistemological position that

advocates the requirement to understand the differences between people (and problems) within a social environment whereas objectivism as an epistemological assumes a realist position. An interpretive paradigm is a metaphysical philosophical position which is concerned with understanding the way people within in a social framework understand the world around them.

Morgan (2014:1053) states that regardless of whether your research is quantitative or qualitative or mixed method, pragmatism can be adopted as a philosophical approach. Morgan (2014:1053) and Dewey (1925b/2008:372) advocate that pragmatism must be seen as 'freedom of enquiry' where researchers have the ability to define and relate to issues and matters that are most relevant to them. Morgan (2014:1053) also argues that it can apply to a practical approach, integrating different perspectives to help create, assemble, and interpret data. Thus, pragmatism for Morgan (2014:1053) accentuates that all phases of research intrinsically rely on the approaches to objectives and methods which are most suitable (Morgan, 2014:1053; Dewey, 2008/1925b:372).

Creswell and Plano Clark (2007:59) suggest that mixed methods research is useful for assessing whether there are converging or diverging views from different data collection strategies, and that through the process new inferences can be made. The researcher's study is located within the pragmatic mixed method objectivist approach, where qualitative methods are given higher priority than quantitative methods. This approach is a parallel mixed method research design, utilising triangulation to verify and analyse solutions of the phenomena studied (see Figure 1.4).



**Figure 1.4: Parallel mixed method design**

Source: Adapted from Creswell and Plano Clark (2007:59)

### 1.3.3 The researcher's axiology

Axiology can be defined as the role of morals, values, and ethics within the research analysis. It involves how researchers reflect their own morals and values. In addition, it also applies to how the researcher deals with the research participants (Saunders *et al.*, 2009:87).

A pragmatic mixed method research axiology suggests that the researcher assumes both an insider and outsider's perspective to fully understand the issues being studied. This involves a level of inclusion and dialogue with the communities being studied, ensuring that different views and opinions are captured within the study. However, the researcher acknowledges that he is closer to the insider position, and because of this perspective, the researcher accepts that the outsider position could well be less prominent. In studies on the insider-outsider debate, Chabra (2020:307) has put forward the view that a rigorous insider-outsider researcher's position cannot be sustained and that one cannot fully occupy both positions simultaneously.

The researcher is aware that the selection of both the qualitative and quantitative design within the pragmatic approach must be carried out to obtain the maximum diversity of viewpoints. In other words, 'multiple ways of making sense of the social world and multiple standpoints on what is important and to be valued' (Greene, 2008:78). A pragmatic mixed method approach has, as a key objective that the study should be of mutual benefit to business, people, and society, as well as the development of new knowledge.

## **1.4 Research problem**

The global electricity sector remains unpredictable and variable, especially in the context of structure, governance, and technology. Whilst the policy framework for the industry has been drafted (International Energy Agency, 2016:87), it appears to be incongruent with electricity demands and technological needs. Thus, one of the problems that this research aimed to address was the lack of congruence between electricity utilities and future technological needs.

It is suggested that by developing a holistic and systemic technology roadmap platform, the learning and the framework developed could create an improved approach to sustainable long-term technology strategies for electricity utilities. Technology roadmaps and associated approaches comprise a new and evolving field of science. This is particularly true for global electricity utilities (Phaal, 2007:10; EPRI, 2020:8). Important drivers behind the formulation and management of an industry wide technology programme include:

1. The convergence of the 4<sup>th</sup> and 5<sup>th</sup> industrial revolution of telecommunications, artificial intelligence and related information technologies.
2. Continued restructuring of the global electricity supply sector.
3. The need for investment in new power plants, as well as demand-side measures to meet market demands.
4. The needs for shareholder returns and investors for secure investments.
5. Environmental regulations, policy, and legislation mandating continual improvement in performance impacting current and new technologies.

6. Variable economic conditions applying pressure on research and development (R&D) and strategic technological development.

As a result of increased globalisation pressures impacting on the electricity sector, critical technological strategies result in businesses reacting in a short-sighted linear thinking approach (Schainker, 2007:27). It is the researcher's view that this results in fundamental strategic business weaknesses, as the technological innovation process is seen as sequential and short-term, and with no long-term sustainability; i.e. design to production and then market, whereas all stages should progress within a systemic paradigm understanding the holistic view of the world and the interconnectivity of the system and sub-systems (Lundvall *et al.*, 2011:45).

In many industries, technology product lives are shortening; this makes it imperative that time to market is kept to a minimum. While a close relationship between R&D, design, and production has always been important, it must now be recognised as an increasingly important element in the innovation process (Hamilton and Mitchell, 1988). However, the researcher suggests that this process should not result in reductionist or linear thinking, which possibly could lead to the detriment of the business due to the ever-changing conditions of the market and the environment.

Therefore, given this background, the problem that this study intended to address was the inability of current technology strategies and technology roadmapping to predict the future needs of the electricity industry.

## **1.5 Research aim and objectives**

### *1.5.1 Aim*

The principal focus of the study was to develop a conceptual technology roadmap framework that would create significant value for the long-term technology sustainability for electricity utilities. This is especially critical with respect to the processes of technology applications, strategic technology planning, risks, and implementation.

Thus the overarching research aim of this study is,

*To develop a conceptual framework for technology roadmapping that is responsive to an ecosystem where the rate of technological adaptations and changes outpace business processes.*

### 1.5.2 Objectives

The objectives are as follows:

**Objective 1:** To critically evaluate current roadmapping methodologies in order to determine the links with utility technology and absorptive capacity.

**Objective 2:** To determine the key elements and drivers for a systemic/holistic framework.

**Objective 3:** To determine the reasons, shortcomings and lack of congruence between electricity utilities and future technological needs in the current technology roadmapping process.

**Objective 4:** To construct and develop a conceptual framework for technology roadmapping that is responsive to a contemporary electricity utility.

## 1.6 Research questions

In keeping with the aim of this study, the following questions are posed:

**Table 1.1: Research questions (RQ)**

<p><b>Problem statement: The problem that this study intends to address is the inability of technology strategies and roadmapping approaches to predict the future use and needs of the electricity industry.</b></p>	
<p><b>Aim:</b></p> <p>To develop a conceptual technology roadmapping framework that is responsive to an environment where the rate of technological adaptations and changes outpace business processes.</p>	<p><b>Primary research question:</b></p> <p>What is the nature of a technology roadmapping framework that is responsive to an electricity utility environment where the rate of technological adaptations and changes outpace business processes?</p>
<p><b>Objective 1:</b></p> <p>To critically evaluate current roadmapping methodologies in order to determine the links with utility technology and absorptive capacity.</p>	<p><b>Research question 1:</b></p> <p>How do the current roadmapping methodologies link with electricity utility technology and the firm's ability to recognise the value of new technological information, assimilate it and apply it for commercial gain (absorptive capacity)?</p> <p>Sub-question:</p> <p>What is the nature and value of current roadmapping methodologies?</p>
<p><b>Objective 2:</b></p> <p>To determine the critical elements and drivers for a more systemic/holistic framework.</p>	<p><b>Research question 2:</b></p> <p>What are the critical elements and drivers for a more systemic framework?</p>
<p><b>Objective 3:</b></p> <p>To determine the reasons and the extent of the shortcomings of the current technology roadmapping processes.</p>	<p><b>Research question 3:</b></p> <p>What are the shortcomings and limitations of the current technology roadmapping framework?</p> <p>Sub-questions:</p> <p>What is the nature of the lack of congruence between electricity utilities and future technological needs?</p>

<p><b>Objective 4:</b></p> <p>To construct a conceptual framework for technology roadmapping that is responsive to an electricity utility.</p>	<p><b>Research question 4:</b></p> <p>What are the critical constructs of a conceptual technology roadmap that is capable of responding to an electricity utility environment?</p>
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The primary question was studied and examined in detail through the development of a Systemic Technology Roadmapping Framework and a thorough understanding of the design process approach. Several research questions have been formulated to help seek a deeper understanding of the application of the framework. These research questions are considered as starting points to guide the research.

## 1.7 Research design

Research is the systematic analysis of data collected, scrutinised, and questioned in order to fully comprehend, develop, describe, and formulate positions (Creswell, 2003:37). It is important to note that both quantitative and qualitative data are useful in understanding business performance and behaviour. Thus, for a researcher to gain knowledge, the study depends on the theoretical framework and ontological and epistemological stance; i.e., the research paradigm. Research paradigms are distinguished by ‘how researchers make claims about what knowledge is (ontology), how research is obtained knowledge (epistemology), what values go into it (axiology), how one writes about it (rhetoric) and the process for studying it (methodology)’ (Creswell, 2003:37).

The mixed method approach was deemed most appropriate for this study. It is based on the researcher’s paradigm, which is aligned with the research problem and while the researcher leans towards an objectivist stance, the study required a subjectivist stance in order to construct a conceptual framework. The researcher’s epistemology of how knowledge was gained will be through the application of a systems thinking approach, which is aligned with the aim of the study (i.e., a conceptual framework for a holistic for technology roadmapping), and pragmatism which supports the problem-solving stance of the design.

Generally, quantitative approaches tend to be associated with the positivistic paradigm, employing strategies of inquiry such as survey studies and methods of data collection that are subjected to statistical data measures. Qualitative approaches, on the other hand, are associated with constructivist or the transformative-emancipatory paradigms which employ strategies such as case studies or data collection by way of interviews resulting in open-ended textual data.

The mixed method research approach is associated with the pragmatic paradigm and strategies that involve collecting data in a simultaneous or sequential manner. The methods are drawn from quantitative and qualitative data sets in a fashion that best addresses the research question (Creswell, 2003:37). As deliberated by Creswell (2003:37), the differences between mixed method and multi-method research are pinned on their ontological and epistemological assumptions. The researcher's view in overcoming the differences is to assume a pragmatist stance.

The development of mixed method research over the last decade has evolved in a number of directions (Teddle and Tashakkori, 2009:18; Creswell and Plano Clark, 2017:23). Mixed method design may be both flexible and situational depending on a researcher's approach to a study (Creswell and Plano Clark, 2007:59; Teddle and Tashakkori, 2009:18) and not linked to a particular mixed method paradigm.

The researcher is aware (as mentioned earlier) that mixed methods can be mixed as long as they share an ontological perspective, in that these methods both view the nature of the world in the same way. As suggested by Guba and Lincoln (2005:191), they do not see any fundamental problem with mixing methods as long as a researcher does not mix paradigms (world-views). Thus, the key differentiator is the understanding of methods as opposed to methodologies. Methods are mechanical processes for collecting and analysing data, whereas methodology (or design) is related to paradigms - ways in which to implement methods in the context of a specific world view (Guba and Lincoln, 2005:191).

## **1.8 Ethical considerations**

Confidentiality is a critical ethical component of this study and informed consent is of paramount importance. The researcher conducted structured and semi-structured workshops and quantitative surveys with international members of an international electricity research and development institute. Workshops or focus groups, also known as group interviews, as described by Gibbs (2012:31), are defined as organised interactive dialogue sessions with a selected group of individuals in order to gain opinions on a research topic.

At no time did the researcher place the individual members and the institute at risk or harm in terms of inappropriate publications or breach of the individuals' and institute's confidentiality. Thus, the researcher briefed the institution by way of a solicitation letter (see Appendix 1) that the members would be protected, and consent was obtained before the start of the research from the IRO. Further, all references to the participants and collective focus group feedback have been kept anonymous with specific codes, for example  $A_n \dots A_{n+1}$  for members comments and  $A_g$  for shared focus group comments.

## **1.9 Scope and limitations of the study**

The primary area of this research study focused on the development of an alternative conceptual framework for technology roadmapping for electricity utilities and their future technological needs. A limitation of this study relates to a restricted set of data available due to a relatively small population for the study.

In addition, because of the researcher's background in technology management, the researcher could also be biased, which could have resulted in researcher-induced bias. Thus, the researcher aimed to mitigate this possible bias by undertaking a mixed method design approach to bring together the strengths of the various qualitative and quantitative techniques and by triangulating the findings emerging from these methods.

## 1.10 Structure of the thesis

The thesis is divided into seven chapters, of which the first chapter is the introduction providing an overview of the objectives and the structure of the thesis. The thesis framework is depicted at the end of this chapter (Figure 1.5).

Chapter 1: Introduction: This chapter deals with the preliminary concepts of the research study. The focus is on explaining the research topic in the context of the status quo. Clarification and explanation of terminology is covered here, as well as introducing the research design and methodology, based on the research problem, aim, and research questions.

Chapter 2: Literature review: A critical analysis and theoretical foundations for this thesis is covered in Chapter 2. The relevant reviews of the literature and a detailed analysis of the evolution and current approach to technology roadmapping is undertaken.

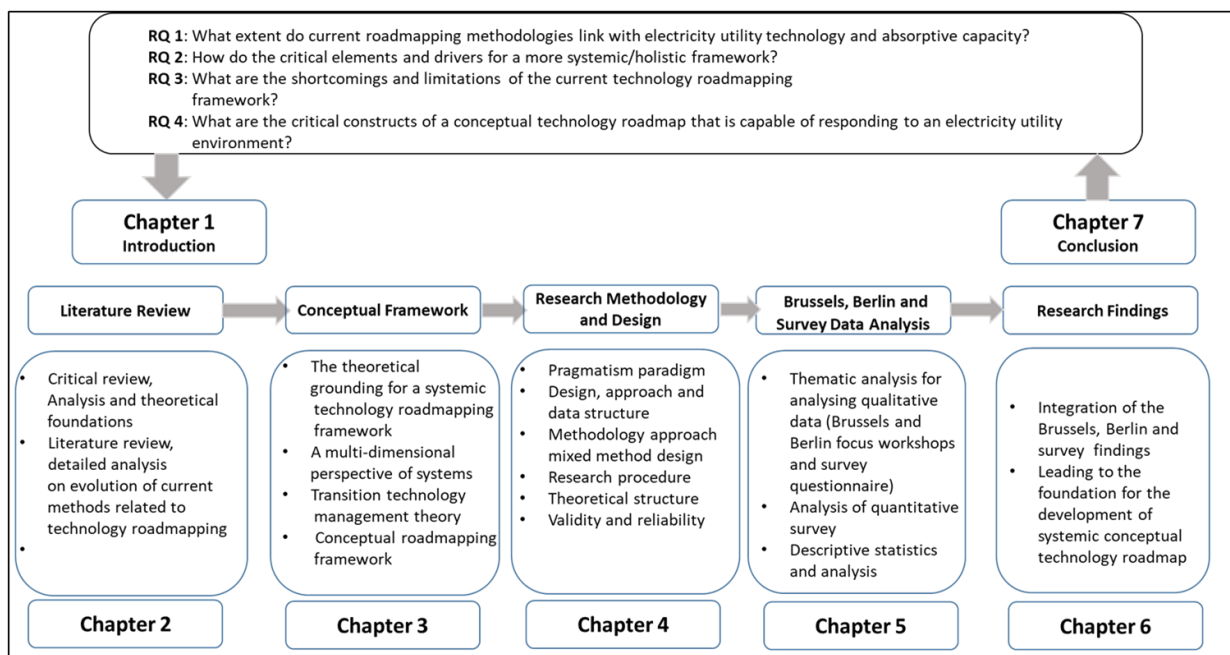
Chapter 3: Conceptual framework: This chapter deliberate on and link the numerous methodologies and theories within current roadmapping theory on roadmapping methods, approaches, and design to develop a draft alternative technology roadmapping framework. Theories include transition management theory and a multi-dimensional perspective of complex systems and systems thinking. This chapter builds on and draws from the comprehensive literature review in Chapter 2, viz., the strategic importance of global technology understanding, current methods and approaches to technology roadmapping, and the importance and impact of technology research and development related to global competitive trends.

Chapter 4: Research design and methodology: In Chapter 4, a precise research design, approach, and the data structure of the study which are used to answer the research questions are described, together with supporting justification drawn from the literature. A description of the methodology selected for the study, namely a pragmatic mixed methods design approach, is outlined. Finally, the development and theoretical structure of a holistic Technology Roadmapping Framework are interrogated.

Chapter 5: Brussels, Berlin and survey data analysis: This chapter provides a thematic analysis approach in analysing the qualitative datasets of the Brussels and Berlin focus groups and the IRO survey questionnaire. Descriptive statistical analysis was undertaken for the quantitative datasets. Supporting secondary qualitative and quantitative data are utilised wherever possible.

Chapter 6: Research findings: This chapter includes the findings of the quantitative and qualitative datasets undertaken amongst the IRO members. A comparative analysis and integration of the datasets are carried out. The analysis and findings test the research aim of the study in terms of convergence and divergence of the datasets and build towards the development of a new conceptual technology roadmapping framework.

Chapter 7: Conclusion: The conceptual technology roadmapping framework will be proposed in terms of the way forward. This is in the form of recommendations and in providing methodologies, processes, and adaptation of organisational-wide technology roadmapping implementation. This chapter will also describe the areas of limitations and will make proposals for future research.



**Figure 1.5: Thesis framework**

## **1.11 Conclusion**

This chapter provided the background and context of the research study. The research objectives were formulated, and a multi-dimensional non-linear systemic approach to technology roadmapping was proposed. The purpose was to develop and provide tools to better equip organisations, executives, technology strategists, and researchers in developing key technology options for the future that would indeed make them globally competitive.

Finally, as in any research study, the path to discovery was not always a straightforward journey. However, the researcher believed that developing a conceptual framework it would significantly contribute to electricity utilities in achieving a more robust approach to defining future technology strategies.

## CHAPTER 2

### LITERATURE REVIEW

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#### 2.1 Introduction

This chapter presents a critical analysis of contemporary literature regarding technology roadmapping. The review was undertaken to provide a robust and deep understanding of the various theoretical perspectives, concepts, drivers, and methodologies of the technology roadmapping process. In addition, gaps and weaknesses are identified in the literature. Wherever possible, in the next chapter, these are addressed by developing a holistic/systemic theoretical conceptual framework for technology roadmapping and informing the research methodology of this study.

The characteristics and practices of technology management within electricity utilities are central to understanding the development of technology roadmaps. This chapter also attempts to answer the questions; 'What is the nature and value of current roadmapping methodologies?' and, 'To what extent do current roadmapping methodologies link with electricity utility technology and absorptive capacity?'

Technology roadmapping has evolved and matured and, in many cases, has become the strategic lens for the technology revolution of the past decades (Phaal and Muller, 2009:39; Phaal, 2014:8; Kerr and Phaal, 2020:16). Thus, this theoretical analysis will ultimately improve the understanding of the technology roadmapping and technology adoption practices.

The term 'roadmap' is used freely by planners and appears to have a variety of meanings (Kostoff and Schaller, 2001:143). However, the most commonly accepted definition of a roadmap was first cited by Robert Galvin, the former CEO of Motorola (Galvin, 1997:26):

*A roadmap is an extended look at the future of a chosen field of inquiry composed from a collective knowledge and imagination of the brightest drivers of change in the field.... Roadmaps communicate visions, attract resources from business and governments, stimulate investigations and monitor progress. They become the inventory of possibilities for a particular field.*

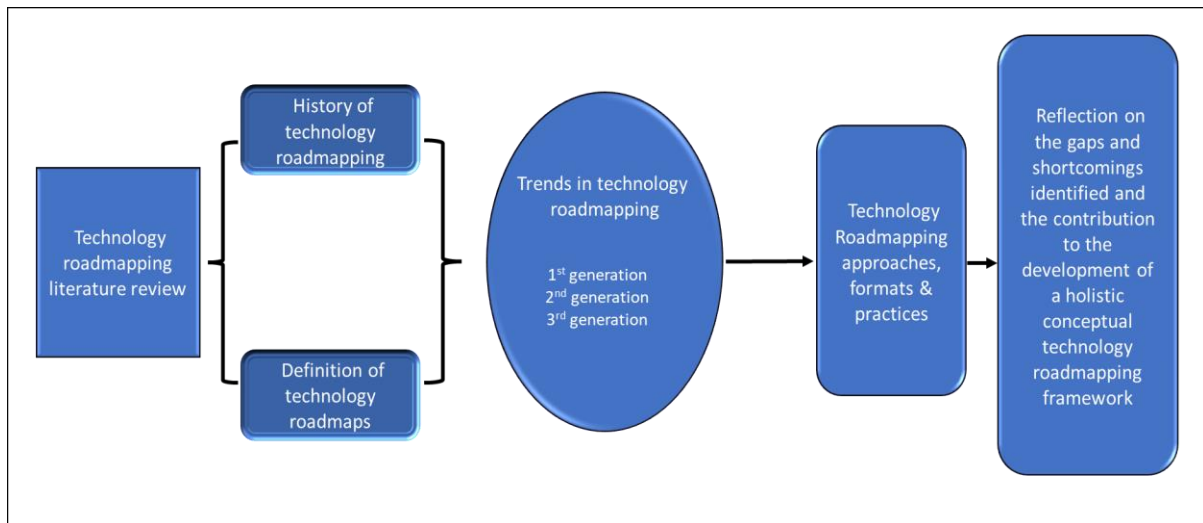
Thus, a technology roadmap is not only a plan but also a vision of future technology research and actions. It is evident that the existing roadmapping solutions and tools have been developed in business areas where the commercial focus dominates, and as such, not enough attention is given to 'emerging technologies' and 'creative inventions' (Carvalho, Fleury and Lopes, 2013:1437; Letaba, Pretorius and Pretorius, 2017:8; Tierney, Hermina and Walsh, 2013:194; Farrukh and Holgado, 2020:15).

According to Li-Hua (2009:22) and Kerr and Phaal (2020:16), the traditional practices of management by nature are not always pertinent to technology planning. Despite companies being conscious of the strategic importance of planning new technologies, not all move in this direction, and in most cases, have difficulty incorporating technology knowledge into their management practices. Notwithstanding the widespread usage of technology roadmaps internationally, there has been little or no consideration paid to the theory and practice of roadmapping in the published literature (Schaller and Kostoff, 2001:132; Kappel, 2001:39; Kamtsiou and Olivier, 2012:25; Phaal, 2014:8; Kerr and Phaal, 2020:16).

This chapter reviews and conveys some general understanding of technology roadmapping and practices. The chapter also reviews the general roadmapping definitions and the classifications and taxonomy of roadmaps. In addition, this chapter provides a synopsis of technology roadmapping methodologies and practices from an evolutionary perspective and identifies shortcomings and gaps to initiate the development of a systemic conceptual technology roadmapping framework.

As shown in Figure 2.1, the chapter has been divided into five parts: a) the history of technology roadmapping, b) a literature review of roadmapping definitions, c) a review of roadmapping process models and an evolutionary perspective of the various

generations of technology roadmapping, d) a review the different technology roadmapping formats, processes, and approaches, and e) identification of the various gaps and shortcomings in the literature.



**Figure 2.1: Literature review map**

## 2.2 The history of technology roadmapping

Technology roadmapping was first initiated by Motorola in the 1970s as a process model to map out knowledge flows (technology and products) visually. Motorola's view was that developing technology roadmaps would significantly assist the organisations in integrating the business strategy and technology strategy in terms of improved business performance, technology planning, risk awareness, competitiveness, and future sustainability (as cited by Willyard and McClees, 1987:19).

Phaal *et al.* (2001:374) and Kamtsiou (2016:106) reviewed over 1000 industry-level (government bodies and agencies' and research institutes') roadmaps in various fields, including technology, energy, defence, manufacturing, electronics, and others. At the time, industry-level roadmapping generally applies foresight methods, scenario planning, and Delphi techniques to describe views of future states and then defines suitable actions. In contrast, business and commercial approaches are predominantly

focused on product development and organisational roadmaps (Phaal *et al.*, 2013:17; Kamtsiou, 2016:106; Letaba, 2018:75; Kerr *et al.*, 2019:60).

Examples of industry-led technology roadmaps which applied foresight and Delphi-based techniques were the roadmaps for the semiconductor industry and several European Union funded projects, for example, PROLEARN, which was a roadmap that looked at the future practice of technology for enhanced professional learning and bridges which reviewed the design and performance of future bridges (Kamtsiou and Olivier, 2012:25, Kamtsiou, 2016:106).

Motorola published its first technology roadmap (Park *et al.*, 2020:139), which described a 10-year planning horizon for the car radio, focusing primarily on the product planning approach. Following the Motorola approach, several electronic companies, including Lucent Technologies and Philips, adopted the technology roadmapping approach to define and plan future product development (Park *et al.*, 2020:139; Kerr and Phaal, 2022:15). Since the development of the first published roadmap paper by Motorola, most roadmapping studies were undertaken by companies with the primary approach of product development (Phaal *et al.*, 2004:12; Gerdri, Kongthon and Vatananan, 2008:2132; Kerr and Phaal, 2022:15). However, in the last decade, technology roadmapping has evolved into a research discipline where academia explores sophisticated methods in the systematisation process and implementation approaches (Ilevbare *et al.*, 2011:17; Kamtsiou, 2016:106; Letaba, 2018:75; Kerr and Phaal, 2022:15).

### **2.3 Roadmapping definitions**

Technology roadmapping as an academic and research field is growing from a fundamental process of looking at technology from an organisational perspective to a more vigorous information and knowledge gathering process in dealing with multifaceted technological and innovation systems (Phaal *et al.*, 2001:374; Farrukh, *et al.*, 2014:62; Kerr and Phaal, 2022:15). It is important to note that the words 'technology roadmapping' and 'technology roadmaps' are frequently used interchangeably.

The term 'roadmapping' describes the process that assists in the design and approach to implementing innovation and technological plans that meet future market trends and conditions. The 'roadmap' is a visual representation or product generated from the roadmapping process (Garcia and Bray, 1997:24; Igartua, Albors and Hervas-Oliver, 2010:52; Vojak and Chambers, 2004:139; Phaal, 2014:8; Kerr and Phaal, 2017:277; de Alcantata and Martens, 2020:28; Kerr and Phaal, 2020:16).

The seminal work of Galvin (1997:26) provides the most widely used definition of roadmapping which states that,

*'A roadmap is an extended look at the future of a chosen field of interest composed from the collective knowledge and imagination of the brightest drivers of the field'.*

There are numerous definitions of technology roadmapping, and the following are some definitions presented by well-known researchers:

*Technology roadmapping is a needs-driven technology planning process to help identify, select and develop technology alternatives to satisfy a set of product needs. It brings together a team of experts to develop a framework for organising and presenting the critical-planning information to make the appropriate technology investment decisions and to leverage those investments (Garcia and Bray, 1997:24).*

*Roadmaps are both forecasts of what is possible or likely to happen, as well as plans that articulate a course of action. Roadmaps can be used to align organisations in time of predictable change, but have limited insight into disruptive change (Kappel, 2001:15).*

*Roadmaps focus portfolio and business planning for the future (McMillan, 2003:38).*

*The technology roadmap is defined as a medium and long-term technology planning methodology to derive products and know-hows that need to be*

*developed to meet the future demand and to select the best alternative technologies based on future market forecasts (Jin, Jeong and Yoon, 2015:85).*

A more recent definition is:

*Roadmapping is the application of a temporal-spatial structured strategic lens (Kerr and Phaal, 2022:15).*

From the above, it is apparent that roadmapping is predominantly a market-driven consensus process with the primary objective of identifying new future products and services for company roadmaps, and the industry or sector roadmaps investigate and explore new technology trends in terms of long-term planning. Thus, we can accept that roadmapping is a collective strategic planning process that enables organisations to utilise tacit and explicit knowledge to facilitate long-term technology planning (Kappel, 2001:39; Phaal and Muller, 2009:39; Jin *et al.*, 2015:138; Letaba, 2018:75; Kerr, *et al.*, 2019:60; Kim *et al.*, 2019:6657; Son *et al.*, 2020:20; Malinga and Oosthuizen, 2021:11). As Gerdsri *et al.*, (2008:2132) mention, technology roadmapping is a process that aids in developing and executing innovative plans to manage the changing landscape of technology, market trends, and new business opportunities.

Several researchers describe roadmapping as a *process* rather than a *tool* (Garcia and Bray, 1997:24; Kostoff and Schaller, 2001:143; Kappel, 2001:39; Farrukh and Holgado, 2020:15; Malinga and Oosthuizen, 2021:11). Thus, the process takes the form of a number of interactions between experts and stakeholders. However, Phaal (2011:6) and Kerr and Phaal (2022:15) define technology roadmapping as a *tool* that enables organisations to make future strategic decisions based on technology futures, risk minimisation, and competitive positioning.

Thus, from reviewing the various definitions from the literature, it can be seen that technology roadmapping has been extensively applied as a technique across a broad spectrum of users, including companies, governments, academics, and researchers across industries. However, what is clear is that a standard approach and

methodology of technology roadmapping does not exist and that there are substantial differences among users as to what characterises a roadmap and how to assess the usefulness of the technique applied (Koenig, 1999:174; Lee and Park, 2005:583; Kamtsiou, 2016:106; Letaba, 2018:75;). To quote Radnor (1998:43),

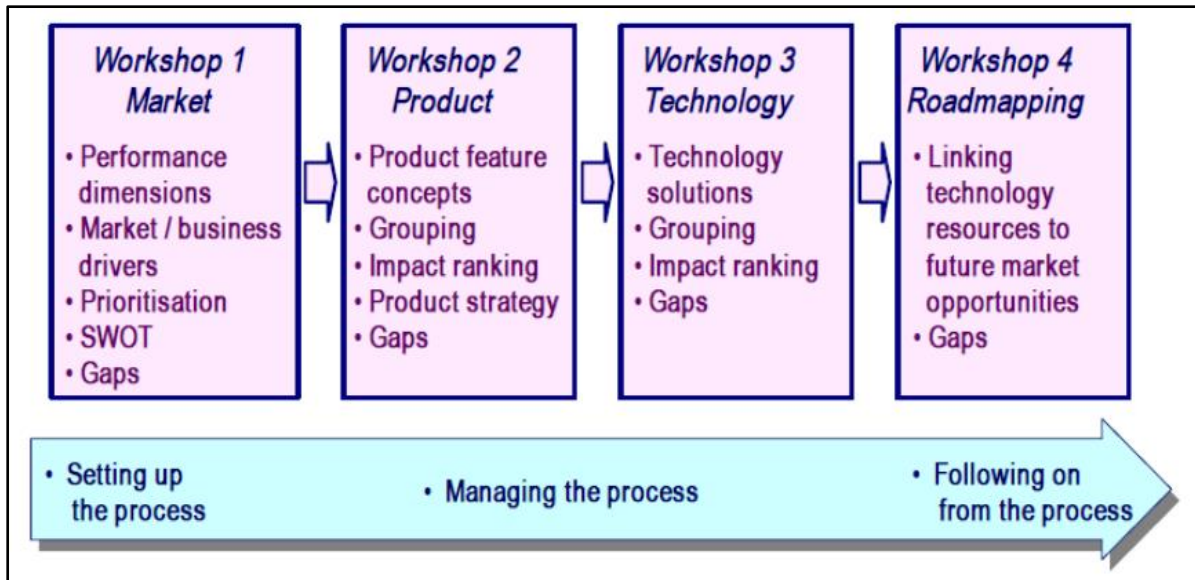
*Companies want to mechanize roadmapping, but much of it remains off the books. Roadmapping is political and involves negotiation and re-negotiation and, as such, there is little evidence (except for T-Plan and Strategic Technology Alignment Roadmapping {STAR}) of detailed explanations of methodologies for developing roadmaps.*

To quote, (Kamtsiou, 2016:117),

*Roadmaps have been criticized for lacking analysis of socio-economic trends and social requirements, hence roadmapping methodologies are not usually connected to social contexts and that there is an obvious lack of focus on risk and uncertainty in the roadmapping methodologies.*

Ger. (2000:25; 2016:12) proposed a T-Plan methodology, which focuses on a fast-start technology roadmapping approach which is still applied today in a number of organisations (Figure 2.2) (Letaba, 2018:75). There are four engagements which are divided into individual themes addressed in several workshops. The first workshop focuses on key market and business drivers, reviewing current gaps and obstructions from a performance perspective, followed by workshop two, where potential product options and grouping of products are selected and gaps identified. It is then followed by workshop three, where solutions are sought, and products are ranked in terms of importance.

Finally, in workshop four, resources are identified and aligned with future markets, followed by a gap analysis. However, the T-Plan technology roadmapping process resembles many other roadmapping processes in the literature, and in addition, it lacks one critical aspect in that it disregards any follow-up activity (Letaba *et al.*, 2017:15). See Figure 2.2 below:

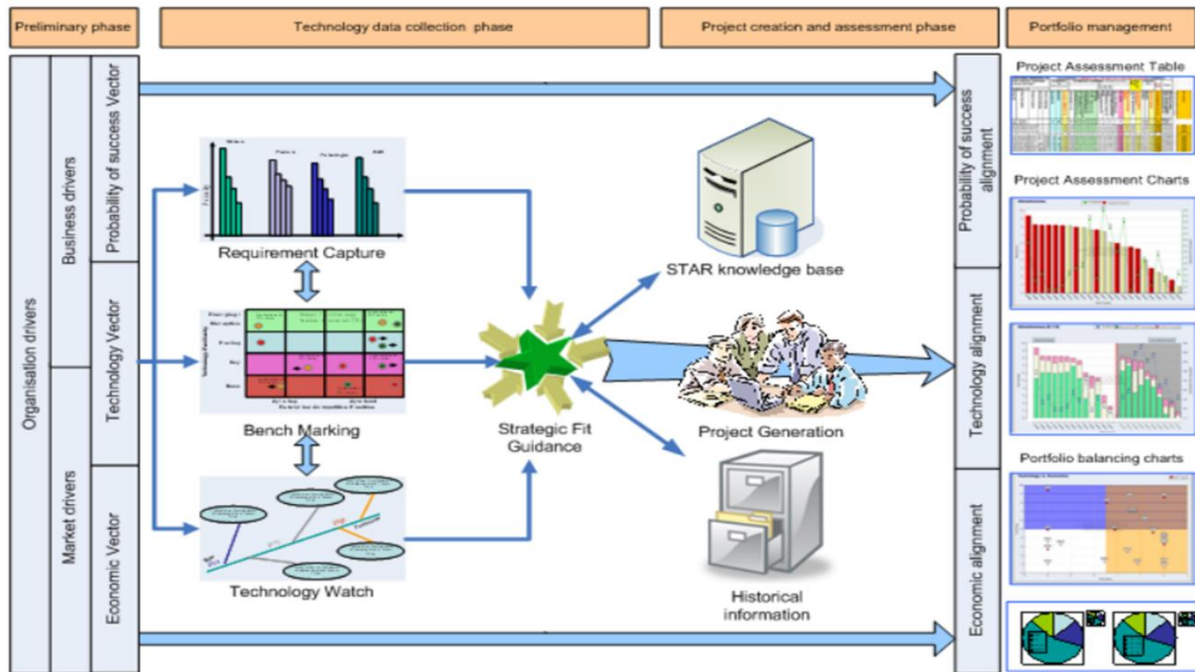


**Figure 2.2: T-Plan fast-start technology roadmapping process**

Source: Phaal et al. (2000:25)

A vastly improved fast-start technology roadmap is the S-Plan, which is also workshop-based and entails a three-phased approach; planning, a workshop, and then a review (Phaal et al., 2013:17; Phaal et al., 2016:12; Letaba 2018:75; Kerr and Phaal, 2022:15). The S-Plan approach emphasises strategic planning as its core, and its primary focus is on organisational technology strategy and innovation processes integrated into the technology roadmapping methodology (Ghazzawi and Cook, 2015; Kamtsiou, 2016:106; Kerr and Phaal, 2022:15) to enable organisations to align their business, R&D investments, and technology acquisition programmes.

The Strategic Technology Alignment Roadmap (STAR) developed by Gindy, Moros, Cerit and Hodgson (2008:42), has a four-phase approach; the first phase is concerned with setting an enterprise framework followed by a technology data gathering phase, a project creation and a review and assessment phase; and a fourth workshop is a project management phase (Figure 2.3). The integrated enterprise-level roadmapping methodology, as applied in the STAR methodology, offers an impartial way of selecting and evaluating technology projects (Gindy et al., 2008:23).



**Figure 2.3: The STAR methodology framework**

Source: Gindy et al. (2008:23)

Regardless of the specific methodology, we can see that the process of technology roadmapping is a methodology involving a participatory strategic planning process that leads to the development of a technology roadmap. The value of the roadmapping process relies on its ability to create a consensus-building approach among the stakeholders within the organisation, sharing both explicit and tacit knowledge to create new knowledge (Li and Kameoka, 2003:392; Yasunga and Yoon, 2004:585; De Oliveira et al., 2020; Park et al., 2020:139; Son et al., 2020:20; Kerr and Phaal, 2022:15).

The researcher suggests, based on the current roadmapping shortcomings (lack of ecosystem understanding) (Kamtsiou, 2016:106), that there is a need to consider further a more holistic and systemic approach to the roadmapping process, where complexities of the ecosystem are fully considered and integrated.

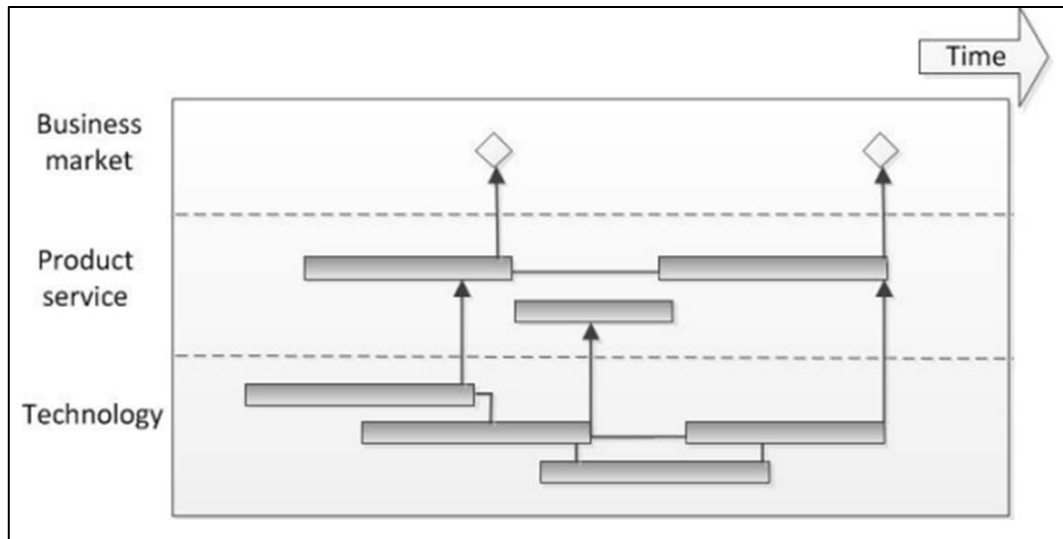
## 2.4 Trends in technology roadmapping

Technology roadmapping has evolved from a rudimentary process that studied, reviewed, and concentrated on technology outcomes within an organisational planning process to a more vigorous and dynamic knowledge-gathering process for the understanding, forecasting, and management of complex technological systems (Phaal *et al.*, 2013:17; Son *et al.*, 2020:20; Kerr and Phaal, 2022:15). Consequently, technology roadmaps have been classified into three evolutions; first, second and third generation (Gindy *et al.*, 2008:23; Kostoff, Boylan and Simons, 2004; Tierney *et al.*, 2013:211; Kamtsiou and Olivier, 2012:25; Kerr and Phaal, 2020:16). The following few sections trace the evolution of these roadmaps.

### 2.4.1 First generation technology roadmaps

First generation roadmaps (the 1970s to mid-1980s) focused primarily on managing product improvement issues and are utilised by companies and organisations. These roadmaps' primary aim was to accurately focus on technology forecasting, continuous technology improvement efforts, and single root technology (Gindy *et al.*, 2008:23; Tierney *et al.*, 2013:211). According to Kostoff *et al.* (2004:159), first generation technology roadmaps are usually associated with processes to improve the performance of existing products using existing product technology processes.

Thus, these roadmaps are less complex and apply linear and incremental innovative processes for improvements for a single product or technology, and these maps move innovations along a single trajectory over time. The significant contribution of first-generation technology roadmaps was the basic or generic roadmapping structure (Figure 2.4) (Kostoff and Schaller, 2001:143; Kostoff *et al.*, 2004:159; Kamtsiou and Olivier, 2012:25; Kerr and Phaal, 2020:16).



**Figure 2.4: Schematic example of a first generation roadmap**

Source: Phaal *et al.* (2001:374)

Emergent technology roadmaps are also classified as first generation and are generally driven by new and emerging technologies which are evaluated against the current state of technology. The difference between product technology and emergent roadmaps is that emergent roadmaps focus on product platforms rather than product roadmaps and product market forces (Garcia and Bray, 1997:24; Park *et al.*, 2020:139). In addition, emergent technology roadmaps focus on predicting potential technological opportunities that would positively position a company's competitiveness in the market. Data mining is a critical component in categorising emergent technologies and the development of appropriate technology trajectories (Walsh, 2004:185; Phaal *et al.*, 2016:12; Letaba, 2018:75).

Thus, for first generation technology roadmaps, the belief and view are that past technological trends in performance could well prescribe and indicate future technological performance, assuming that the current environment remains unchanged (Vojak and Chambers, 2004:139; Kamtsiou and Olivier, 2012:25; Park *et al.*, 2020:139).

#### 2.4.2 *Second generation technology roadmaps*

Second generation roadmaps (the 1980s-1990s) primarily set out to advance the approach of technology strategic planning and to investigate the future impact and potential value of disruptive technologies for organisations (Bucher, 2003:122; Gindy *et al.*, 2009:970; Walsh, 2004; Kamtsiou, 2016:106; Letaba, 2018:75). Second generation roadmaps are distinguished as emerging disruptive roadmaps and, compared to first generation roadmaps that 'do not have single cell technology to advance or fixed market targets or a stable process paradigm and but are still generated from a single root technology' (Tierney *et al.*, 2013:211).

Instead, second generation roadmaps are used in identifying current changes in the product platform or to recognise likely potential new applications enabled by emerging technologies. Thus, they assist in charting technology trends in several critical domains by applying multiple technology lifecycle approaches. However, it is essential to note that second generation roadmaps do not address 'multiple root technologies, constraints from drivers other than market drivers or new business models' (Tierney *et al.*, 2013:211; Kamtsiou, 2016:106; Letaba, 2018:75; Park *et al.*, 2020:139).

According to Walsh (2004:185) and Kamtsiou (2016:106), the fundamental difference between first and second-generation roadmaps is that first generation roadmaps focus on a solitary or single technology that competes against a single outdated or traditional technology. In the case of second generation roadmaps, the focus is on a cluster of disruptive technologies competing against a variety of current technology solutions 'with the aim to creatively destroy existing technology product market paradigms' (Walsh, 2004:185).

#### 2.4.3 *Third generation technology roadmaps*

Third generation roadmaps (1990s-present) are primarily aimed at integrating technology management, where technology roadmapping is incorporated into the business processes, models, and strategies of companies; however, it is still in the

development stages (Bucher 2003:122; Gindy *et al.*, 2009:970; Kamtsiou, 2016:106; Letaba, 2018:75; Yoon *et al.*, 2019:73).

Furthermore, third generation technology roadmaps acknowledge the rapid development and changing landscape of various technological innovations shaped by various drivers (Tierney *et al.*, 2013:211; Kamtsiou and Olivier, 2012:25; Kamtsiou, 2016:106; Letaba, 2018:75). In addition, these technological innovations can drastically impact the strategic pathways of organisations and industries; thus, a comprehensive understanding of the nature and impact of these pathways is crucial in developing third generation technology roadmaps.

Third-generation technology roadmaps' key outputs convey and communicate critical technological conditions and options related to business processes, markets, and product intelligence (Lee and Park, 2005:583; Amer and Daim, 2010:1370; Phaal *et al.*, 2013:17; Kamtsiou, 2016:106; Letaba, 2018:75; Kerr and Phaal, 2022:15). An important differentiator of third generation technology roadmaps is that it disregards product-process platforms and meso-level drivers (Tierney *et al.*, 2013:211; Kamtsiou, 2016:106).

According to Kamtsiou (2016:106), the weakness of the current approach of third generation roadmaps is the lack of meso-level understanding in the roadmapping process, as new innovations are occurring and converging at the interfaces of more than one technology, rather than a linear view of technologies individually. Thus, these roadmaps aim to provide a generic picture of the evolution of technologies for industries rather than at a more specific product level of implementation.

In summary, this section has identified several evolutionary phases and generations of technology roadmapping. The three generations describe and characterise the various research archetypes and are dependent on the planning horizon being considered by the various users. It is suggested that established companies with the appropriate infrastructure would tend to favour using the product-technology (first generation) or emerging technology (second generation) roadmapping methods, while multi-national companies and countries are more than likely consider third generation

technology roadmaps in terms of applying a technology foresight approach (Kamtsiou, 2016:106; Letaba, 2018:75; Romaski *et al.*, 2021:107; Kerr and Phaal, 2022:15).

The current weaknesses of the third generation roadmaps, as described by Kamtsiou (2016:106), highlights the importance of ensuring that a new approach and design in the roadmapping approach needs to be considered. This study aims at developing a more conceptual systemic framework required to handle the current deficiencies highlighted in the third generation roadmapping methodologies.

## **2.5 Technology management**

Technology can be considered as an explicit type of knowledge, distinguishing itself from more general knowledge types with the vital characteristic that it is applied, focusing on the application and capability of the organisation. While technology is usually related to science and engineering, the approaches which allow its effective application and use are also important; for example, new development and innovation processes, together with organisational structures and supporting knowledge networks (i.e. the 'soft' aspects of technology) (Van Wyk, 2017:14).

Technological management and knowledge generally comprise both explicit and tacit knowledge. Explicit knowledge is that which has been coded, reported, and shared (for example, in a report or procedure, together with the physical manifestations of technology (equipment)). Tacit knowledge cannot easily be articulated and relies on training and experience (Cetindamar, Phaal and Probert, 2016:240).

There are several definitions of technology management in the literature. For example, the European Institute of Technology Management proposes the following definition (as cited by Phaal *et al.*, 2004:12):

*Technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies needed to maintain a market position and business performance in accordance with the company's objectives.*

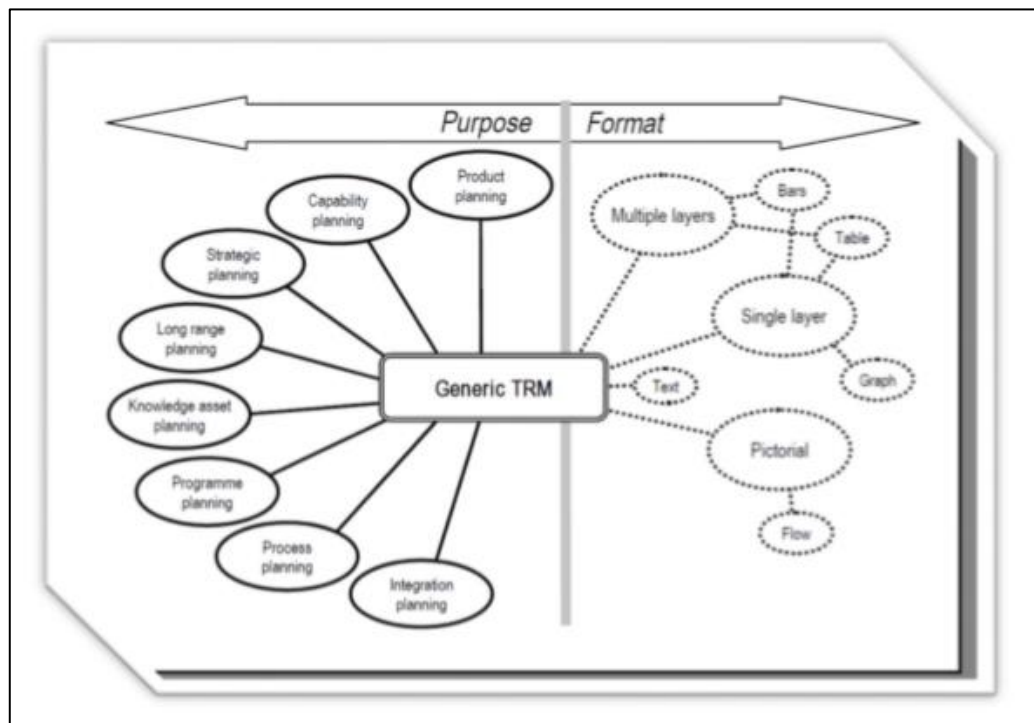
This definition highlights two central management themes; firstly, establishing and maintaining the linkages between technological resources and company/organisation objectives is of vital importance and represents a continuing challenge for many organisations, which requires an effective communication and knowledge management strategy (Phaal *et al.*, 2013:17; Asim & Sorooshian, 2019:21). Of particular importance is the dialogue and understanding that needs to be established between the commercial and technological functions in the business.

Secondly, effective technology management requires several management processes; identification, selection, acquisition, exploitation, and technology protection (Phaal *et al.*, 2004:12; Mahammad *et al.*, 2019:1599). However, these processes are not always visible in firms and are typically distributed within other business processes, such as strategy, innovation, and operations.

Technology management is a process that is required to maintain a market stream of products and services. It deals with all aspects of integrating technological matters into business decision making and is strategically relevant to business processes such as strategy development, innovation, and operational management. Strong technology management requires creating appropriate knowledge flows between commercial and technological perspectives in an organisation in order to accomplish a balance between market pull and technology push (Cetindamar *et al.*, 2016:240; Kerr and Phaal, 2022:15).

These concepts are illustrated in Figure 2.5, indicating the generic technology roadmapping approach for supporting technology management and planning in the firm. Phaal *et al.* (2001:374; 2016:12) describe the various categories of technology roadmaps and different formats. As shown in Figure 2.5, the roadmaps are categorised into eight categories; product planning which is associated with the development of new generation technologies; capability planning which is closely linked the Teece's (2007:1350) capability theory in support of organisational capabilities; strategic planning linked to the vision of an organisation; long-range planning; and knowledge asset planning linked with organisational knowledge management practices, programme planning, process planning, and integration

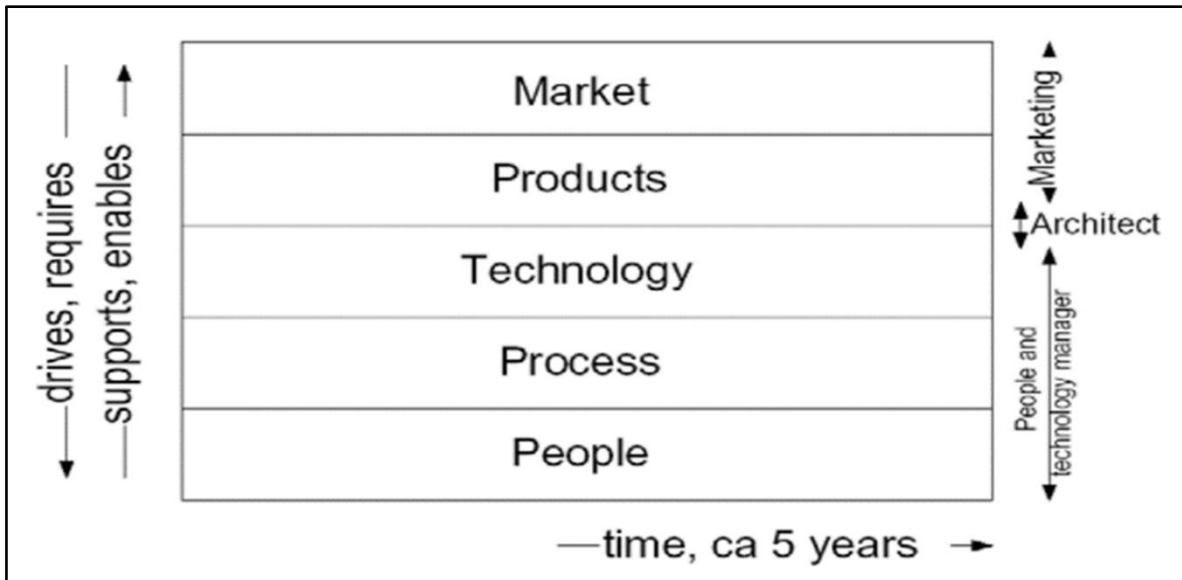
planning of future technologies into organisations' future business model (Phaal *et al*, 2001:374; 2016:12).



**Figure 2.5: Characterisation of technology roadmaps, purpose and format**

*Source: Phaal et al. (2016:12)*

A framework presented by Muller (2007:21) for technology roadmapping is given in Figure 2.6. The figure indicates that the market is the critical driver for the products, technology, processes, and people. Thus people, processes, and technology enable the products and support the market's needs, and the framework can be seen as bridging the two extremes, namely market pull and technology push.



**Figure 2.6: Framework for technology roadmapping**

Source: Muller (2007:21)

### 2.5.1 The role of transition management theory in technology roadmapping

Transition Management Theory (TMT) fundamentally views the world systemically in its approach to sustainable planning. Transition theory is about understanding the behaviour and dynamics of complex systems and sub-systems continuously interacting and adapting. For example, in the Netherlands, nationally sponsored programmes have increasingly adopted methods of transition management (Kemp and Loorbach, 2006:35; Loorbach *et al.*, 2017:626).

In the United Kingdom (UK), studies concerning policy relevance are being studied and promoted through newly developed projects and events comparable with those supported by the Economic and Social Research Council's Sustainable Technologies Programme (Shove and Pantzar, 2005). From an academic perspective, there has been rapid growth in the transition management literature (Shove and Pantzar, 2005; Loorbach and Van der Lindt, 2007; Loorbach *et al.*, 2017; Letaba *et al.*, 2017:15; Loorbach, 2022:41).

As a result of these interactions, new patterns materialise at different levels that alter the conditions to which individuals and organisations will adapt, resulting in ongoing changes and transformations. These changes continue in an ongoing fashion until an equilibrium is reached for a period until the next wave of transformation occurs. It is important to note that these changes exhibit non-linear characteristics which develop as events which can reinforce each other. This systemic relationship is fundamental in applying transition management theory (Loorbach and Van der Lindt, 2007:21; Geels and Schot, 2007:417; Van der Brugge, 2005:35; Loorbach *et al.*, 2017:626; Loorbach, 2022:41). Usually, TMT is predominantly used in strategic planning and, more recently, in technology roadmapping (Letaba, 2018:75).

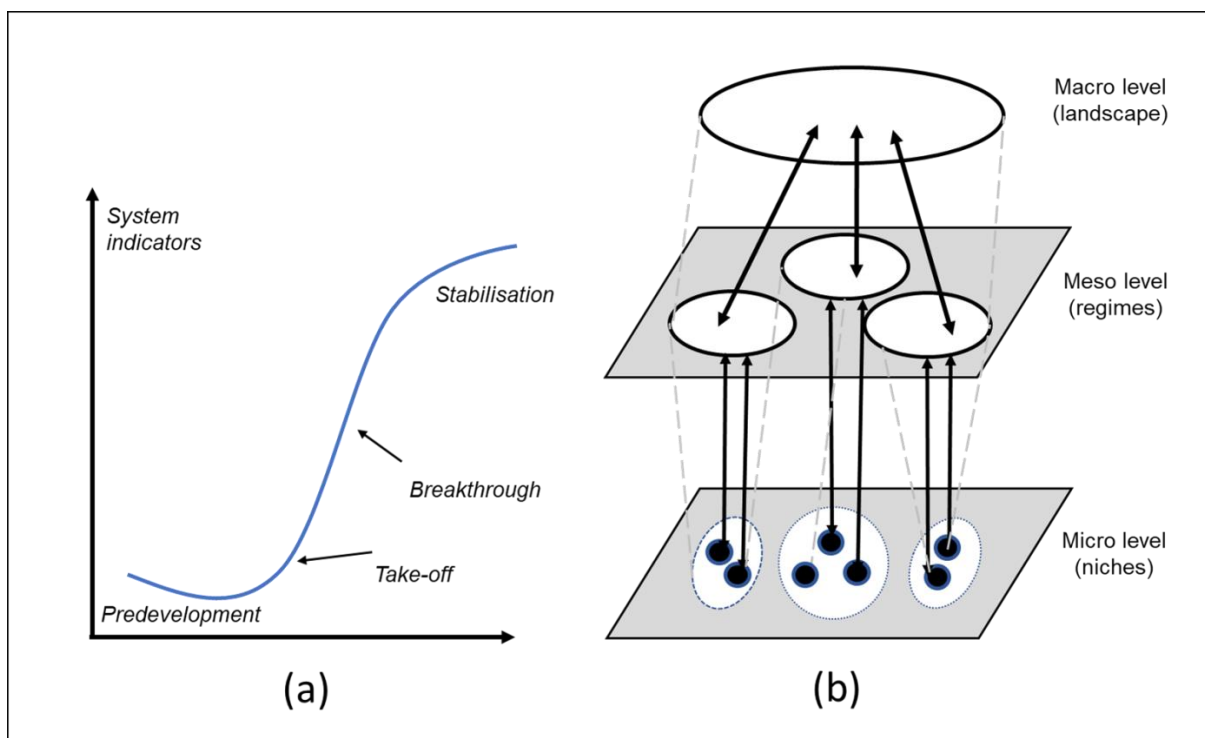
The basic concept of transition management relies on the approach that the world is interconnected and that organisations need to view the world from a systemic perspective due to continuous changes in the socio-technical and technological systems (Letaba, 2018:75; Loorbach, 2022:41). Systems move from established paradigms to new ones, and organisational planning needs to consider technological and social innovations. Social innovation is the process of defining appropriate solutions to problematic and often systemic social and environmental issues in the provision of social progress (Pol and Ville, 2009); for example, the development of appropriate/low-cost water sterilising technology for underdeveloped rural applications.

Studies on societal innovations and transitions (Geels and Kemp, 2000:7; Van der Brugge *et al.*, 2005:27; Verbong and Geels, 2006:1037) propose that transition varies from one subsequent stage to another, and the nature and speed of the changes vary from one transition to another. Figure 2.7 shows the S-Curve and indicates the rate of change through the various stages of a technology cycle. The first stage during the early development phase transition remains relatively stable even though the social landscape is slowly adapting to the new innovation. This phase occurs predominantly at the micro-level.

In the take-off and breakthrough phases, change occurs significantly faster than in the previous phase, and the state of the system (meso-scale level) and the system begins

to modify. This system acceleration results in structural changes and increased interaction on the socio-cultural, economic, ecological, and institutional practices. Once the stabilisation phase is reached, the societal change decreases, and a new equilibrium is achieved (Van der Brugge, 2005:35; Loorbach *et al.*, 2017:626; Loorbach, 2022:41).

Currently, the literature highlights the limited approach of applying and integrating transition and complex systems concepts in technology roadmapping studies (Phaal *et al.*, 2001:374; Tierney *et al.*, 2013:211). However, it is the researcher's view that key constructs of the TMT model can be integrated into the development of a conceptual technology roadmapping framework.



**Figure 2.7: Multi-phase and multi-level concepts of transition**

Source: Adapted from Loorbach *et al.* (2017:626)

### 2.5.2 Technology roadmapping formats and levels

Technology roadmapping is a high-level plan and a decision-making process communicating an organisation's technology strategy. It looks at the future to anticipate what will happen and what has to happen to move ahead. It provides a consensus vision of the technological landscape ahead, as well as pathways to identify, evaluate, and select alternative paths that can be used to achieve the organisation's objectives (Schaller & Kostoff, 2001:132; Kerr *et al.*, 2019:60; Farrukh & Holgado, 2020; Park *et al.*, 2020:139; Kerr & Phaal, 2022:15).

Roadmapping and its outcomes (the roadmap) can enhance communications and consensus achievement within an organisation and with external parties. In addition, it has the potential to provide information to make better decisions by identifying critical R&D areas of high potential or strategic value and technology gaps when it is not clear which technology alternative to pursue, how and when technology will be available, or when it is necessary to coordinate the development or acquisition of multiple technologies (Schaller & Kostoff, 2001:132; Kamtsiou *et al.*, 2014:27; Farrukh & Holgado, 2020:15; Park *et al.*, 2020:139; Kerr & Phaal, 2022:15).

To quote Schaller and Kostoff (2001:132),

*Technology Roadmapping differs from other methods of technology planning and forecasting due in large part to its inherent practical nature. A roadmap is not a prediction of future breakthroughs in science or technology, but rather an articulation of requirements to support future technical needs.*

Thus a technology roadmap defines or adopts an agreed future and then provides an approach to reaching it (Schaller and Kostoff, 2001:132).

According to Kerr and Phaal (2022:15) roadmaps can be defined as a structured visual chronology of an organisation's strategic lens, as they provide a robust and practical means of supporting their strategy, long-term technology development, and innovation activities. The underlying architecture of a technology roadmap reflects how an

organisation views itself and how its business will be transformed into the future (Phaal *et al.*, 2013:17; Phaal, 2014:8; Kerr and Phaal, 2020:16; Kerr and Phaal, 2022:15).

Technology roadmaps can be viewed as a dynamic time-based measure and provide a sense of 'when' actions are planned, unlike many strategic management tools, which tend to disregard time as a critical variable (Kerr and Phaal, 2022:15). However, it can be seen as critical and is anchored by the following questions (Phaal *et al.*, 2007:12; Phaal and Muller, 2009:39; Kerr and Phaal, 2020:16; Kerr and Phaal, 2022:15): Where do we want to go? Where are we now? How can we get there?

To further expand on this, Ackoff (1999:177), in his seminal book on corporate design for the 21<sup>st</sup> century and a pioneer in the area of operations research and systems thinking, describes the planning approach of idealised design and interactive planning along with the terms ends planning and means planning (Ackoff, 1999:177; 1970:8). In the context of roadmapping, Ackoff's (1970:8) and cited by Kerr and Phaal (2020:16) term, 'ends planning' relates to *Where do organisations want to go?* and means planning relates to *How do we get there?* Furthermore, it is still relevant today.

Kerr and Phaal (2022:15) proposed the governing technology roadmap framework as a temporal-spatial strategic lens showing the time dimension on the horizontal axis moving from the current state into the future. As one moves towards the future, uncertainty increases, which in many cases is often overlooked by businesses (Kerr and Phaal, 2022:15). The timeframe of the roadmap is context-dependent and adapted according to an organisation's unique situation (Phaal *et al.*, 2004:12).

The timeline is divided into four segments: the present, which is the current state and may include particular essential elements of the past that have led to the current state. Short-term is generally defined and scaled to the organisation's budget horizon (Kerr and Phaal, 2022:15), whereas medium-term can be considered the option the organisation can make to effect change. The long-term considers plausible futures and scenarios and unconstrained opportunities. The final timeline is the vision, which clearly articulates the question, Where do we want to go?

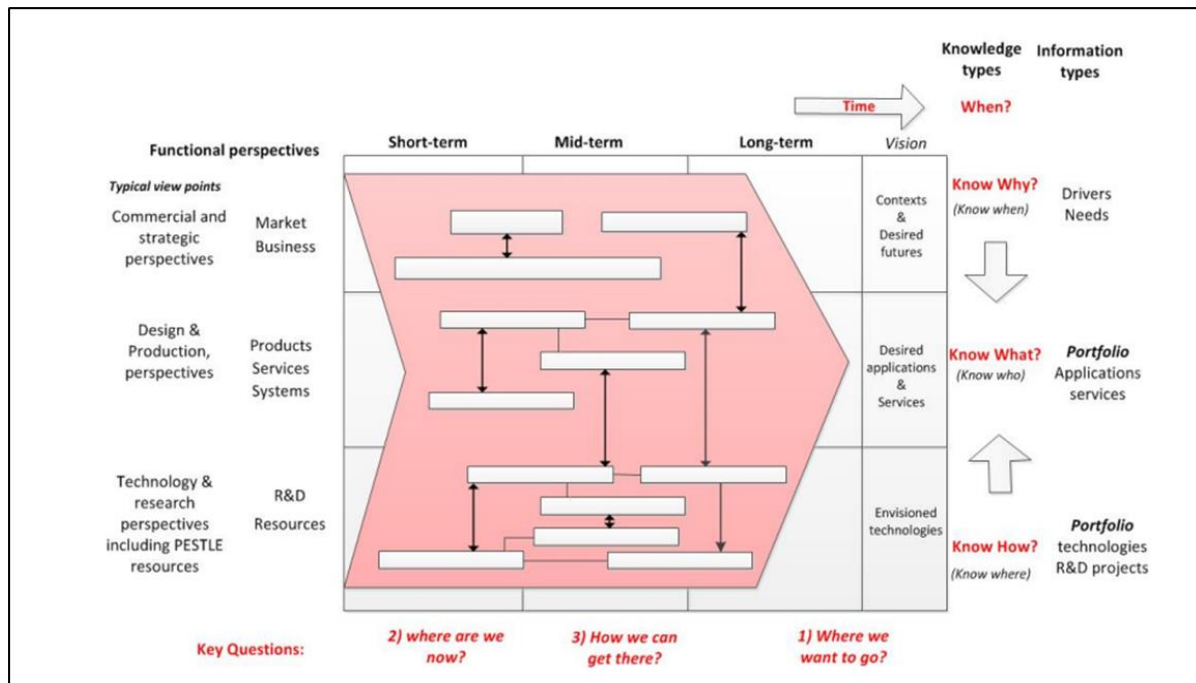
Phaal *et al.* (2001:374) and Farrukh, Clive, Phaal, Athanassopoulou and Routley (2014:62), introduced into the governing framework in an elementary manner (Figure 2.7) of a multi-layered structure by assigning the features of know-why, know-what, and know-how to the vertical layers, and know-when to the horizontal time axis. In addition, Phaal *et al.* (2001:374) pose several questions for the spatial dimension; Why do we need to act? What should we do? How should we do it?

It is these key questions that set the foundation for the governing framework. To quote Dovoudi (2015:7), 'planning can be viewed as a practice of knowing, and intent is knowing to what end'. Thus, strategic intent can be viewed as the vision of the future (Long., 1993:13; Ackoff, 1999:177; Phaal *et al.*, 2013:17; Kerr & Phaal, 2022:15). Thus, a roadmap can be defined as a structured visualisation of an organisation's strategic intent.

If one considers generic highway maps, a technology roadmap is similar in that they theoretically consist of markers and links. It is important to note that the links can display both quantitative and qualitative characteristics. For example, a marker in a roadmap could signify the qualitative characteristic of the impact on an innovation study that could hypothetically impact the future technology outcome. A quantitative marker could be the time estimate for that innovation or associated technology to be incorporated into the planning phase of the roadmap. The standard technology roadmap consists of spatial and sequential dimensions (Farrukh *et al.*, 2014:62; Kamtsiou, 2016:106; Letaba, 2018:75; Kerr *et al.*, 2019:60; Kerr and Phaal, 2020:16; Kerr and Phaal, 2022:15).

The figure (Figure 2.8) shows, from a time-based perspective, a map of the integration and relationships of the key drivers; the technological competence and skills driver; and the product, services and market drivers (Kerr *et al.*, 2009:60; Farrukh *et al.*, 2014:62; Kerr and Phaal, 2022:15). The top layer primarily focuses on the competitive and strategic drivers and is concerned about 'why' the roadmap is being developed. Thus, business, market, and competitive intelligence are critical, along with analysis related to customer needs, industry perspectives, and organisational strategies.

The middle layer is about the design and technology perspectives, and what technologies need to be considered. Thus the 'know what' is a critical question considered in this layer. Finally, the bottom layer emphasises the technology research and development insights regarding 'how' the organisation's resource capability is structured to develop a portfolio of technological solutions (Kerr *et al.*, 2009:60; Farrukh *et al.*, 2014; Kerr and Phaal, 2022:15).



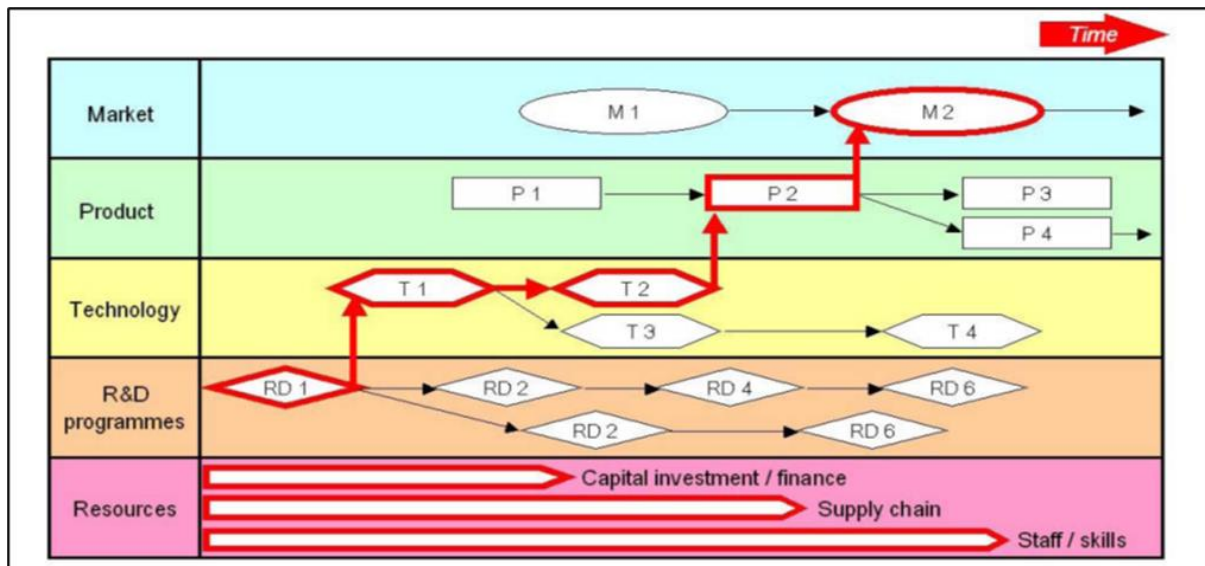
**Figure 2.8: Generic roadmapping framework showing nodes and links**

Source: Adapted from Phaal *et al.* (2001:275) and Farrukh *et al.* (2014:62)

The vertical layers connect the time, purpose, delivery, and resources components (the know-why, know-what and know-how, respectively). The roadmap then defines their relative priorities and then projects them using forecasts to set key indicators. It then links them and synchronises the efforts of the responsible groups in order to justify R&D investments (Farrukh *et al.*, 2014:62; Kerr and Phaal, 2020:16).

Albright and Kappel (2003:40) developed a hypothetical technology roadmap, shown in Figure 2.9. The horizontal axis describes the time domain, while the vertical axis looks at the future market, the product portfolio, and the research and development

resources and capabilities that would enable the technology. The arrows display the timeline of how the future market would be realised through the application of resources, research, and development in developing technologies to meet future market needs.



**Figure 2.9: A hypothetical technology roadmap**

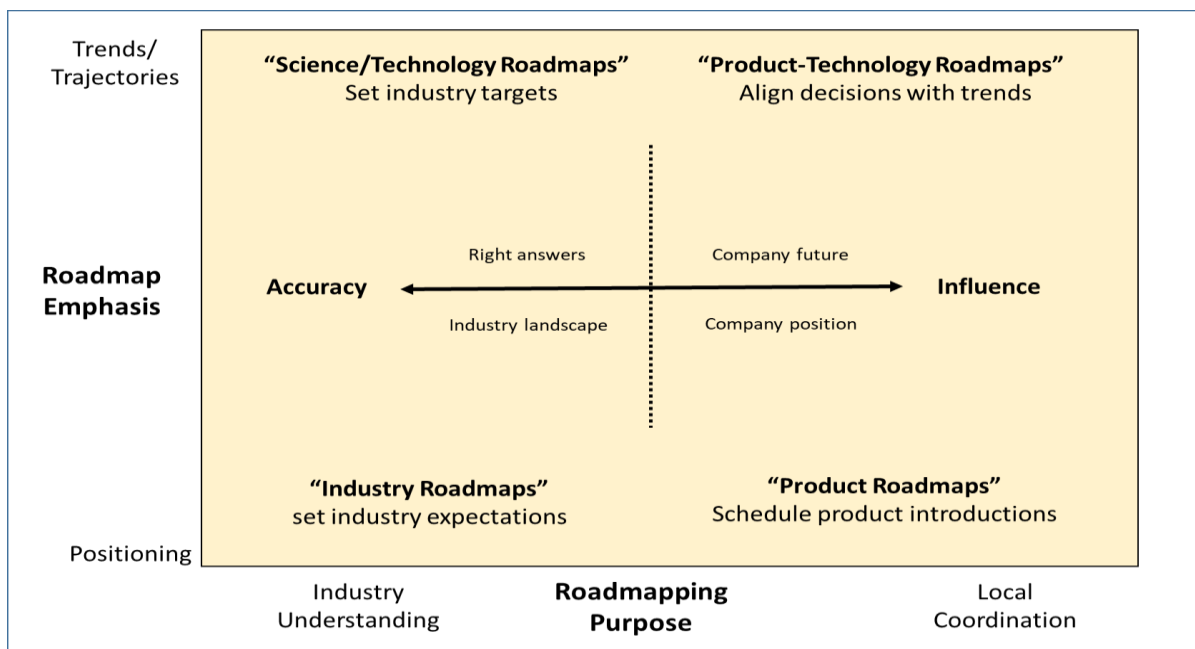
Source: Albright and Kappel (2003:40)

According to Radnor and Probert (2004:27) most firms, particularly technology-centred firms, are gradually implementing product and technology type technology roadmaps (Radnor and Probert, 2004:27). However, research undertaken by Carvalho *et al.* (2013:1437) reviews the literature and highlights in their conclusion that many publications are still in the exploratory phase. In addition, they find that the boundary roadmapping, knowledge management, innovation, and human dimension are insufficiently addressed (Carvalho *et al.*, 2013:1437). However, a substantial quantity of industry-based material is available in the literature (Kappel, 2001:39; Kostoff *et al.*, 2004:159; Phaal, 2014:8; Kamtsiou *et al.*, 2014:25; Kerr and Phaal, 2022:15).

The seminal work of Albright and Kappel (2003:40) developed a taxonomy that categorises roadmaps according to users' specific objectives and requirements

(Figure 2.10). The horizontal axis of Albright and Kappel's taxonomy distinguishes roadmapping intent, e.g. industry level or company level. The vertical axis distinguishes the roadmaps themselves in terms of requirements. The figure shows on the lower quadrants the positioning of trajectories from an accuracy and influence perspective.

The four types of technology roadmaps are shown in terms of their taxonomy, namely: (i) industry roadmaps for developing industry wide opportunities in the bottom left quadrant, (ii) in the bottom right quadrant product roadmaps (introduction at product level only) focused predominantly on company's competitiveness (short-term), (iii) in the top right hand quadrant product-technology roadmaps are aligned with long-term technology futures, and finally (iv), in the top left hand quadrant science-technology roadmaps for developing sustainable national long-term industry goals.



**Figure 2.10: Roadmapping taxonomy**

Source: Albright and Kappel (2003:40)

The industry roadmaps have a business context and typically articulate a technical thrust of the dynamic competitive business environment. The necessity for an intercompany agenda, a complex supply chain, and significant capital investment drive

the requirements for industry roadmaps. When plans are integrated with customer and technology trends, the succeeding product technology roadmaps focus on the relationship between product and sequential technology development (Albright & Kappel, 2003:40; Ilevbare *et al.*, 2011:17; Park *et al.*, 2020:139).

Product roadmaps show spatially and strategically the evolutionary development of products to share with stakeholders. These different levels of roadmaps require varying degrees of commitment in terms of time, cost, level of effort, and complexity. A product-technology roadmap is a well-organised, intensive, multi-year business planning procedure in the execution phase (Albright & Kappel, 2003:40; Ilevbare *et al.*, 2011:17; Park *et al.*, 2020:139).

Roadmaps have a number of definitions, as described earlier, in terms of the variety of uses. Thus, defining roadmaps has become somewhat complex in terms of their variety of applications. According to Radnor and Probert (2004:27), the metaphor 'roadmap' has been used in many cases for just about any planning process (Radnor and Probert, 2004:27; Letaba, 2018:75; Kerr and Phaal, 2022:15).

What is apparent in the roadmapping taxonomy is the strong internal focus in terms of the taxonomy positioning and the lack of an aligned ecosystem presence. This is primarily due to positioning the roadmapping purpose from an organisation perspective only, and thus failing to integrate the ecosystem entirely (Cheng *et al.*, 2016:43).

## **2.6 Roadmapping approaches**

The literature and prevailing practices suggest that a standard process for roadmapping does not exist and that roadmapping is commonly adapted to suit a specific purpose (Kamtsiou and Olivier, 2012:25; Kamtsiou, 2016:106, Letaba, 2018:75; Kerr and Phaal, 2022:15). Numerous roadmap variations have been documented based on extensive literature reviews (Kostoff and Schaller, 2001:143; Muller, 2007:21; Phaal *et al.*, 2016:12; Kamtsiou, 2016:106; Letaba *et al.*, 2017:15; Yoon *et al.*, 2019:73; Kerr and Phaal, 2020:16; Son *et al.*, 2020:20; Malinga and

Oosthuizen, 2021:11; Kerr and Phaal, 2022:15). These can be grouped into three major approaches: expert-based, computer-based, and hybrid/customised.

### 2.6.1 *Expert-based approach*

In an expert-based approach, teams of specialists are assembled to explore and identify key technological components and performance indicators in developing a roadmap. The participation of specialists is divided into various technology focus groups, which could comprise a variety of participants from industry, academia, research organisations, and customers to ensure a balance of know-how and opinions (Kostoff and Schaller, 2001:143; Phaal *et al.*, 2016:12; Kerr and Phaal, 2020:16).

This process is somewhat paradoxical in that the appropriate expertise must be employed to develop a roadmap, but the expertise becomes only fully known after a completed roadmap has been completed (Phaal *et al.*, 2016:12; Kerr and Phaal, 2020:16). An iterative roadmap development process is, therefore, essential. Much of the expertise can be assembled in-house for large organisations, and researchers, developers, marketers and others with relevant knowledge of the overall roadmap process can be readily assembled to develop the framework.

At the other extreme, organisations with little expertise in roadmapping, such as venture capital groups or cash-rich organisations that wish to expand their boundaries, require external assistance to develop credible roadmaps. Depending on the purposes for which the roadmap is being constructed, a team of experts can initiate and continue with the process at various stages, the development stage (basic research), the middle stage (technology development), or the end stage (product development), in order to drive the roadmap to its ultimate completion (Phaal *et al.*, 2016:12; Kerr and Phaal, 2020:16).

From a sequential approach for technology roadmapping, two alternative methodologies have been identified, namely, retrospective analysis and prospective analysis (Kostoff and Schaller, 2001:143).

### 2.6.1.1 Retrospective analyses: backward from the present

Backward or retrospective analysis has been used to reveal the achievements and value-add of product investment and to characterise the various variables in successfully implementing the technological outcomes. Two types of retrospective analysis exist. The first one works backwards to highlight critical technological events that led to the development of a product, while the other analysis considers the funding variable as its starting point and then follows the journey forward trajectory to identify the impacts. The reason for the preferred approach in the industry is that data is easier to acquire, and secondly, funders are interested in obtaining value-add by examining the past regarding technology support (Kostoff and Schaller, 2001:143; Muller, 2007:21; Phaal *et al.*, 2016:12).

### 2.6.1.2 Prospective analyses: forward from the present

Prospective or forward analyses have been used to identify technological gaps and opportunities. Their use has been primary in large country-wide developmental programmes, particularly in national programmes, in promoting a shared vision and understanding in a more global context. The literature shows that country's national science and technology roadmapping approaches are leaning toward using this analysis (Schaller, 2004:241; Farrukh and Holgado, 2020:15).

In prospective analysis, two approaches have been utilised. First, looking forward in time from the present is defined as a technology-push, starting with the current research and development portfolio and then using the research portfolio to develop and plan the eventual outcomes in the roadmap the research achieves. An example of this is the Semiconductor Industry Association Roadmap. It was based on a prospective analysis of Moore's Law, based on the exponential growth over 15 years and the impact that it would ultimately have on the semiconductor industry (Schaller and Kostoff, 2001:132; Ming-Yang *et al.*, 2019:170).

When considering the requirements of a pull prospective roadmap, it starts with the preferred technology and then proceeds backwards to identify the critical research and

development requirements, components, and path of the roadmap to achieve the eventual product outcome. Farrukh and Holgado (2020:15), refer to these as 'backward' and 'forward' planning. Backward planning encompasses scheduling out how to achieve a particular target (the technology), while forward planning describes the process of developing current technologies until new targets appear (an incremental approach) (Farrukh *et al.*, 2014:62; Farrukh and Holgado, 2020:15). In backward planning, the direction of analysis is from the future to the present in time, while in forward planning, the direction is from the present forward to the future (top-down or bottom-up, respectively).

Technology push prospective roadmaps begin with current science or technology research and development programmes, which may be technology or requirements-driven. The approach is to identify the research gaps that hinder the advancement of the end product, which could lead to the product's successful launch (Schaller, 2004:241; Letaba, 2018:75; Farrukh and Holgado, 2020:15; Kerr and Phaal, 2022:15).

In a retrospective analysis, timeframes are from decades past to the present, and in prospective analysis, they are from the present to approximately a decade into the future. The timeframes depend solely on what the organisation sees as appropriate regarding planning horizons and its strategy. For example, roadmaps that present more generic technology information typically cover a more extended period than those with more specific data (Schaller, 2004:241; Farrukh, *et al.*, 2014; Kamtsiou, 2016:106).

Retrospective analyses use prevailing data and thus have a higher degree of consistency and reliability than prospective analysis. However, a fundamental shortcoming with this approach is the likelihood of numerous explanations from the existing data. In addition, an important point to note is that the conclusions of the retrospective studies have not yet been accepted unambiguously (Schaller and Kostoff, 2001:132; Schaller, 2004:241; Farrukh *et al.*, 2014; Kamtsiou, 2016:106).

In addition to the two different methods described, organisations use an integrated approach of retrospective-prospective roadmaps, where the focus is on integrating

past developments of technology with the future vision of where the technology will ultimately reside (Kerr and Phaal, 2020:16). According to Kerr and Phaal (2020:16) these roadmaps have been extremely helpful in evaluating ongoing research programmes. These integrated/combination roadmaps deliver a succinct representation of the programme's origins and past development, and give an indication of where the roadmap is heading.

In all the above approaches, the crucial emphasis of the expert-based method is to draw on the contributors' knowledge, information, and experience to individually identify the key relationships, value propositions, and critical technological attributes that would add meaningful contributions to the final roadmap process (Kerr and Phaal, 2020:16).

However, the contradiction of this approach is that the experts developing the roadmap, in many instances, only understand their specific area of expertise and not the bigger picture. Moreover, in most cases, this approach is a top-down driven approach, based on shareholder value and not on understanding the stakeholder requirements (Kamtsiou and Olivier, 2012:25; Kerr and Phaal, 2022:15).

### *2.6.2 Computer-based approach*

In the computer-based approach, extensive scientific, technology, engineering, and product-based databases undergo detailed computer analyses. The databases include numerous published papers, reports, and research studies. Advanced computerised procedures, including computational morphologies, identify numerous technological product areas, and their relative significance is assessed and quantified. Once the computational analysis has been completed, and all the attributes have been quantified, the roadmap is then constructed (Phaal *et al.*, 2001:374; 2013; Phaal *et al.*, 2016:12).

The general feeling is that the computer-based approach has more impartiality (Phaal *et al.*, 2001:374; 2013:17; Phaal *et al.*, 2016:12) in contrast to the expert-based approach, as it does not have discriminatory limitations, constraints, subjectivity, and

personal agendas of the individuals and experts. Furthermore, a key consideration in the computer-based computational analysis is that it does not begin from one point in time (as does the expert-based approach). Instead, its approach is multi-directional in time (either forward or backwards). Furthermore, it continuously generates, integrates, and analyses all data points within the database simultaneously (Phaal *et al.*, 2016:12).

According to Phaal *et al.*, (2016:12) this roadmapping method is more objective and is not affected by the bias and thinking associated with the individual expert's personal views. Generally, computer-based computational analysis has focused primarily on the organisational relationships between science and technology programmes, principally within the spatial domain. This focus is not a conceptual restriction of the method but an implementation limitation due to the employment of different research objectives (Phaal *et al.*, 2016:12).

The computer-based approach is gaining much momentum due to the advent of large applicable textual databases and the effective mining of computational linguistics. However, in the final analysis, even when digital data are produced, human intervention is essential to ensure that the integration and validation of the results are meaningful (Park *et al.*, 2020:139; Kerr and Phaal, 2022:15).

### 2.6.3 Hybrid approach

An area where computer-based systems can enhance the process is to consider introducing interacting experts within the roadmapping practice. As Radnor and Probert (2004:27) point out,

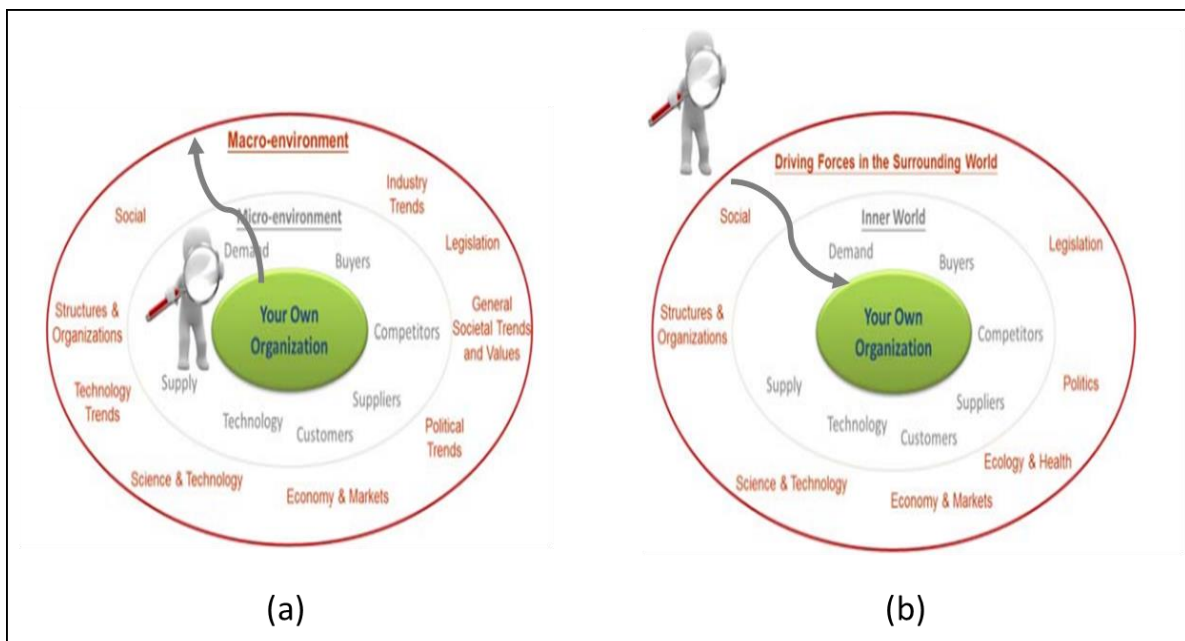
*Companies want to mechanise roadmapping, but much of it remains off the books. Roadmapping is political and involves negotiation and re-negotiation.*

Thus, an integrated approach of combining experts and computer-based systems may reveal an enhanced and more value-adding approach to roadmapping development and outputs than previously realised (Cheng *et al.*, 2016:43; Zhanga *et al.*, 2014). The

standard approach in hybrid technology roadmapping for most organisations is looking at their organisation first and then only considering their customers, competitors and technologies within their own business area (Cheng *et al.*, 2016). In their research on hybrid roadmapping methodologies, Cheng *et al.* (2016:43), conclude that this inside-out perspective (Figure 2.11 (a)) for long-term planning may be inadequate to predict changes in a more complex and competitive business environment.

To anticipate the changes, organisations need to consider external drivers (influences) that could potentially impact their future competitiveness. Thus, an additional approach of an outside-in perspective (Figure 2.11 (b)) is proposed for organisations to incorporate in their long-term technology roadmapping process (Lindgren and Bandhold, 2009:245; Cheng *et al.*, 2016:43).

However, the researcher submits that an optimal roadmapping process can only be achieved if the hybrid roadmapping approach integrates both the inside-out and the outside-in perspectives in the roadmapping development process.

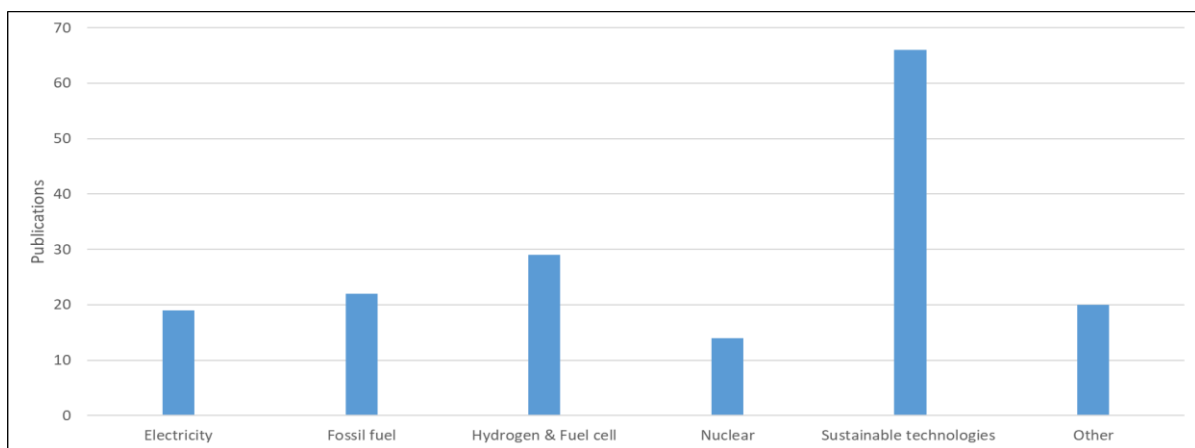


**Figure 2.11: Inside-out perspective (a) and outside-in perspective (b)**

Source: Adapted from Cheng *et al.* (2016:43)

## 2.7 Technology roadmapping in the electricity and energy sector

Over the last decade, there has been a notable increase in activity in technology roadmapping in the electricity and energy sector (Phaal, 2011:6; Bhushan *et al.*, 2015; Kim *et al.*, 2019:6657; IEA, 2021:327). In a detailed breakdown of the electricity sector technology roadmaps, Phaal (2011:11) shows that the areas that dominated roadmapping studies are sustainable energy and hydrogen and fuel cell roadmaps. In addition, there is more prominence in areas related to research and development in the deployment of sustainable technologies in both the public and private sectors (Phaal, 2011:11; EPRI, 2020:8). Figure 2.12 shows the breakdown of public-domain electricity and energy technology roadmaps.



**Figure 2.12: Breakdown of public domain electricity and energy roadmaps**

Source: Phaal (2011:11)

Table 2.1 shows the approach and tools used for the various levels of electricity technology roadmapping. What is highlighted in the table is, except for the industrial sector roadmaps, that both the national and organisational roadmapping approaches fail to apply a macro-system or contextual environmental analysis in their methodology, which is evident by the non-use of PESTLE (Political, Economic, Social, Technological, Legal and Environmental) analysis (Amer and Daim, 2010:1370; Phaal *et al.*, 2013:17; Kerr and Phaal, 2022:15).

A further observation in Table 2.1 indicates that organisations fail to apply risk assessment analysis and a quality function deployment (QFD) survey in their methodology, a set of methods used to define customer needs and requirements. Thus, the ability of organisations to fully comprehend the full impact of the meso or transactional environment on their business is lacking. This is further supported by the fact that internal corporate meetings are seen as a priority. This indicates that there is a strong internal focus on developing organisational technology roadmaps at the expense of fully understanding the relationships of transactional and contextual environments in the organisation itself (Amer and Daim, 2010:1370).

**Table 2.1: Analysis of approaches and tools used in technology roadmaps**

Approach/tools used	National	Industry/Sector	Organisational
Scenario based planning	High	High	Low
SWOT analysis	Medium	Medium	Medium
Delphi	Low	None	None
Expert panels	High	Medium	Medium
Risk assessment	Low	Medium	None
PESTLE analysis	Low	Medium	None
Patent analysis	Low	Low	None
Internal corporate meetings	None	None	High
Citation network analysis	Low	Low	None
Quality function deployment (QFD)	None	Low	None

*Source: Adapted from Amer and Daim (2010:1370)*

In reviewing the literature on electricity technology roadmaps, it is evident that the roadmaps developed are grouped into three main segments in terms of origin: national, industry/sector, and organisational level roadmaps (Amer and Daim, 2010:1370; Letabo, 2018:75).

### 2.7.1 National technology roadmaps

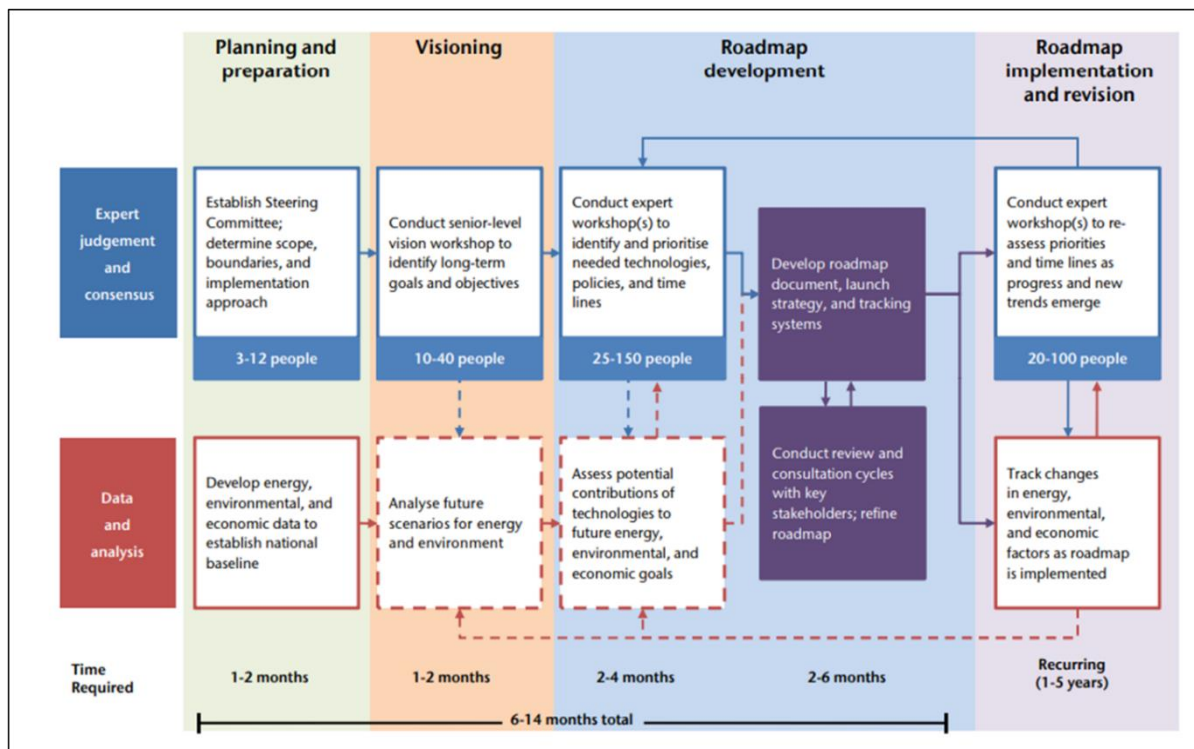
While technology roadmaps were initially used in the private sector, they have been progressively applied by the industrial sectors and governments in terms of national roadmaps. National technology roadmaps generally consider lengthier timeframes than the private sector. Furthermore, national technology roadmaps tend to focus more on developing a framework for public-private partnerships with a view to establishing a direction for the growth of industry and generally consider, in addition to the technological aspects, social as well as political drivers (McDowall, 2012:542; IEA,2014:22; Letaba *et al.*, 2017:15; Letaba, 2018:75).

Thus, national technology roadmaps (third generation roadmaps) provide meaningful insight and understanding to policymakers concerning the future of a country or region's strategic energy needs (McDowall, 2012:542; Letaba *et al.*, 2017:15). The national technology roadmap's primary focus is to develop national goals, visions, targets, energy security, costs, and strategic input to policymakers. In addition, they also provide an essential conduit of strategic information to national organisations and industries involved in energy-related goods and services from a national competitive perspective (Amer and Daim, 2010:1370; Letaba, 2018:75).

An example of a national technology roadmap developed by the International Energy Agency (IEA) is shown in Figure 2.13 (IEA, 2014:22). It has four phases, from planning and preparation to the final roadmap implementation phase, and the development process takes 6-14 months to complete. The roadmap process has a strong involvement of stakeholders throughout the four phases in the form of individual experts. Steering committees are set up, which develop the scope, boundary conditions, and objectives.

Phase two primary objective is to define the roadmap's vision in terms of its long-term objectives and goals. Phase three is concerned with roadmap development with a strong focus on analytics and quantitative analysis. This phase includes several expert workshops and analysis with extensive quantitative modelling. The final roadmapping phase includes the approach to implementation, developing critical key indicators in

terms of tracking and revision (IEA, 2014:22; Londo, Cameron, More, Phaal and Wurtenberger, 2014:243; Letaba, 2018:75).



**Figure 2.13: IEA technology roadmapping process**

Source: IEA (2014:22)

### 2.7.2 Industry and sector technology roadmaps

Industry and sector technology roadmaps are developed together with a number of industries and associated sectors. Research indicates that planning industry technology roadmaps are much easier to initiate, as these organisations have a much stronger network capability within the sector (De Laat, 2004:36; Phaal *et al.*, 2016:12; Kerr *et al.*, 2019:60). Industry technology roadmaps are primarily developed for the industry sector by the industry in terms of providing future vision and technological direction to the industry as a whole.

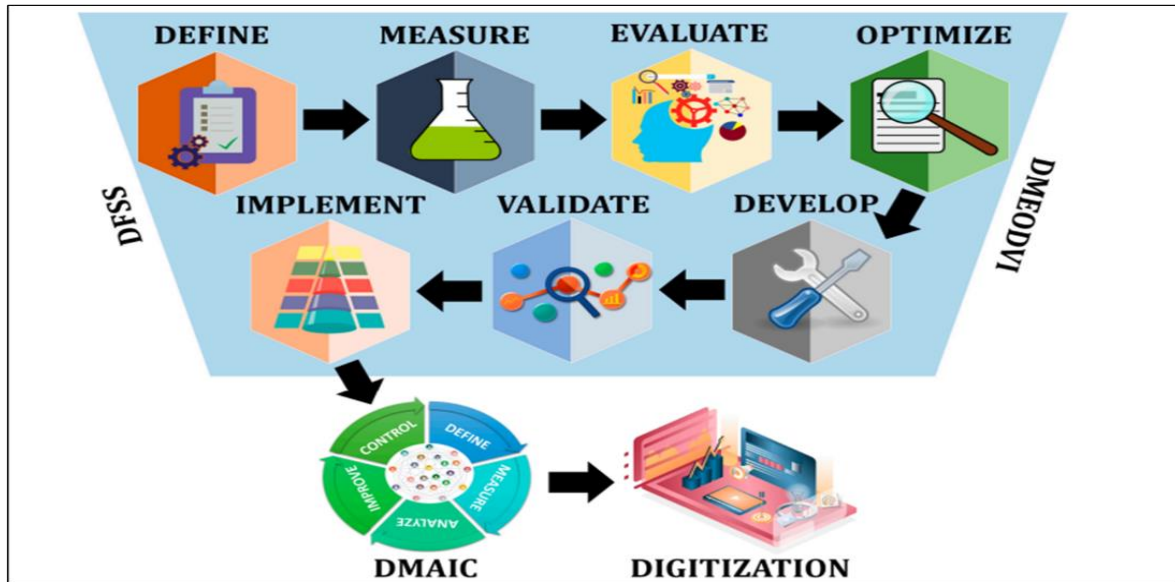
A critical aspect and the strength of the industry technology roadmaps is that they are characterised by a shared and collective knowledge of the entire industry, with the

primary emphasis being the intention for them to be shared across the entire industry. The roadmaps are concerned with identifying industry-wide common and critical technological requirements and facilitating joint collaboration between the industries. The roadmaps are characterised by highlighting the impact of emerging technologies (second generation roadmaps) on the sector and then sharing the road mapping outputs with the industry (Walsh, 2004:185; Kamtsiou, 2016:106).

An example of the industry technology roadmap is shown in Figure 2.14, which is a strategic roadmapping approach that the manufacturing sector could apply (Butt, 2020:30). The roadmapping framework applies the principals of Lean Six Sigma and the design philosophy of Design Six for Six Sigma (DFSS) (Ramayah, Roy, Arokiasamy, Zbib and Ahmed, 2007; Drohomeretski, Gouvea da Costa, Pinheiro de Lima and Garbuio, 2014). The roadmapping framework has, as its basic premise, an approach to redesigning an existing manufacturing process and applies a methodology of defining, measuring, evaluating, optimising, developing, validating, and implementing (DMEODVI) to ensure the application of systematic structure.

A follow-up phase is introduced after the manufacturing transition, where the focus is on continuous improvement of defining, measuring, analysing, improving and controlling (DMAIC) (Butt, 2020:30). It is noted that the roadmapping philosophy, based on the DFSS, is concerned with developing improved technologies and services, whereas DMAIC focuses on the continuous improvement of existing technologies (Butt, 2020:30).

The primary aim is to improve existing products in the manufacturing process in terms of incremental innovations and improved performance. Thus, the dire need to include a broader and systemic approach into the DSFF roadmapping methodology is central to the aim and objective of this study.



**Figure 2.14: Strategic roadmap for Industry 4.0 implementation**

Source: Butt (2020:30)

### 2.7.3 Organisational roadmaps

Organisational technology roadmaps are mainly executing- and action-orientated with critical milestones and deliverables. In a paper by Daim and Oliver (2008:720), they present an approach for implementing organisational technology roadmaps by indicating the significance of integrating company business models with organisational strategies with key drivers and the need to ensure constant monitoring, reporting, and revision. This approach aims to ensure that the maximum organisational benefit is gained from the application and development of emerging technologies identified by the technology roadmap. However, these roadmaps are seldom published as they are viewed as strategic and confidential documents (Phaal *et al.*, 2013:17; Kerr *et al.*, 2019:60).

Company business models and shareholders strongly influence organisational roadmaps, and as such, investments in products and future technologies (first generation roadmaps) are about improving competitiveness, diversification, and exploiting new potential markets for commercial gain. Additional drivers that significantly influence organisational roadmaps are the increased impact of national

government policies, geo-political issues, and risks (Daim & Oliver, 2008:720; Phaal *et al.*, 2013:17; Kerr *et al.*, 2019:60).

## **2.8 Gaps and conclusion**

The literature review and present-day practices indicate that a standard approach, technique, and methodology for technology roadmapping does not exist. In the literature, there are limited detailed descriptions of methodologies for developing roadmaps (Koenig, 1999:174; Lee and Park, 2005:583; Kamtsiou, 2016:106; Letaba, 2018:75; Kerr and Phaal, 2022:15). As quoted by Radnor (1998:32),

*Companies want to mechanise roadmapping, but much of it remains off the book. Roadmapping is political and involves negotiation and re-negotiation.*

Thus, irrespective of the format, they all have similar objectives in that they seek to identify gaps and targets, prioritise key technology development areas related to research and development, and comprise action plans to meet critical priorities (Kamtsiou *et al.*, 2014:25; Letaba, 2018:75; Kerr and Phaal, 2022:15). An output of the roadmapping process is the 'roadmap', a structural visual interpretation of the changing cycle of markets, products and technologies, which emphasises the relations between the various perspectives, resources, and skills. However, regardless of the approach and type of roadmap, they all have common characteristics: they lack the inclusion of a fully integrated ecosystem and systemic understanding in their methodology.

As was evident from the definitions, technology roadmapping is an approach adopted by organisations to plan, align, and manage their business and technology strategy from a market, product, and service delivery perspective (Lee and Park, 2005:583; Phaal *et al.*, 2001:374; Amer and Daim, 2010:1370; Kamtsiou and Olivier, 2012:25; Farrukh and Holgado, 2020:15; Kerr and Phaal, 2022:15). In addition, it is a tactical planning process that allows organisations to develop tangible actions and manage organisational innovation processes.

Technology roadmapping is essentially a needs-driven approach in organisations that explores and identifies new and future technological trends and technologies for its competitive advantage. The success of the roadmapping process is measured by how successfully it can be accepted and implemented by its stakeholders. Thus the value of the roadmapping process lies in its ability to foster and advance consensus building among key stakeholders within a company (Li and Kameoka, 2003:392; Yasunga and Yoon, 2004:585; Kamtsiou, 2016:106; Letaba, 2018:75; Kerr and Phaal, 2022:15).

The three generations of technology roadmapping were reviewed and described, and what was highlighted were the key differences in approach. First generation technology roadmaps were primarily concerned with a continuous product-technology platform based on a single root technology. These roadmaps' main focus was accurate technology forecasting and ensuring improved, cheaper, and enhanced product/technology paradigms. These roadmaps focused primarily on incremental technology innovations (Gindy *et al.*, 2009:970; Bucher, 2003:122; Kamtsiou, 2016:106; Letaba, 2018:75).

The second-generation technology roadmaps' approach was to improve strategic technology forecasting by analysing and researching potential disruptive emerging technologies, and in contrast to first generation roadmaps, do not have a single cell technology to advance or to fix market targets (Gindy *et al.*, 2009:970; Bucher, 2003:122; Tierney *et al.*, 2013:211; Letaba, 2018:75). According to Walsh (2004:185) and Kamtsiou (2016:106), the primary difference between first generation roadmaps and disruptive second-generation roadmaps is that first generation roadmaps concentrate on a single technology versus a single traditional technology.

In contrast, second-generation roadmaps emphasise the collection of emerging technologies competing against several prevailing technologies (Walsh, 2004:185; Kamtsiou, 2016:106). Third generation technology roadmaps are characterised by their recognition that current technology trends depend on the exponential growth of new, competing, multiple-root technologies. A vital characteristic of a third generation roadmap is that it only provides a macro view of technology development at the industry level, accentuating a foresight approach rather than an implementation

approach. This lack of an implementation approach is problematic, as potential beneficial technologies run into problems in that the roadmap fails to convince stakeholders and users of the intended benefits (Kamtsiou, 2016:106; Letaba, 2018:75).

In reviewing electricity and energy roadmaps, various methods and approaches were applied in the developmental process. National technology roadmaps are predominantly issues-based on energy security, policy formulation, and environmental matters, and their primary output is to deliver broad-based strategies. The electricity industry's roadmap's key emphasis is the identification of emerging technologies that would benefit the industry and provide a framework for enhanced public-private partnerships in meeting future sector technology goals.

The current application of technology roadmapping within the electricity industry is based on the application of the third generation approach, which only provides a macro view of technology development at the industry level but ignores the meso-environment view and thus does not fully understand the complexities of the system as a whole (Kamtsiou and Olivier, 2012:25; Kamtsiou, 2016:106; Letaba, 2018:75).

On the other hand, organisational roadmaps primarily focus on the market-products aspects of technology planning and business objectives and are comparatively limited in scope compared with national and industry-wide roadmaps (Amer and Daim, 2010:1370; Phaal *et al.*, 2016:12; Kerr and Phaal, 2020:16; Kerr and Phaal, 2022:15). The analysis of electricity roadmaps has seen a changing trend in approaches and methodologies. They are primarily multiple workshop-based and usually facilitator-guided. The analysis and tools applied in the roadmapping process vary according to the desired level of the roadmap.

In reviewing the literature, a common theme has been identified, in that the approach and methodology to roadmapping has not changed meaningfully over the last decade (Popper, 2008:89; Kamtsiou *et al.*, 2014:25; Kamtsiou, 2016:106). In particular, organisational roadmapping methods are predominately technology-biased and

isolated, and they do not fully grasp the environment's broader impact on their business.

Thus, the potential risk to organisations is that they fail to anticipate the uncertainties around geo-political instability, technological risks, social uncertainty, and the instability of the global economic state timeously. Therefore, the objective of this study is to propose a conceptual framework that considers these uncertainties.

Saritas (2013:117) highlights methodological gaps and shortcomings in the current approach to roadmapping practices and proposes that a systemic approach must be considered in future analytical frameworks. This is based on the foundation that the world is interconnected and interrelated, and due to the exponential growth and convergence in technology, understanding the system holistically is a fundamental starting point prerequisite (Saritas, 2013:117).

This approach aligns with this thesis' objectives in that the critical lenses and research questions are central to closing current gaps, shortcomings, and methodologies of the roadmapping process. Chapter 3 will apply the evolving viewpoints from the literature assessment to develop and deliver an alternate systemic framework for electricity organisations.

## CHAPTER 3

# CONCEPTUAL FRAMEWORK FOR AN ALTERNATIVE SYSTEMIC TECHNOLOGY ROADMAP

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### 3.1 Introduction

The key objective of this chapter was to link with the numerous theories, methods, approaches, and formats reviewed in the previous chapter to formulate a systemic technology roadmapping framework. The aim was to link these various theories with current technology roadmapping theory on roadmapping processes and formats, to derive a holistic conceptual framework appropriate for electricity utilities. It considers the in-depth literature review in Chapter 2, the history and evolution of technology roadmaps, roadmapping approaches, practices and the role of transition management theory in the approach to technology roadmapping. Finally, a meta-model approach was applied to develop the conceptual framework, which evaluates the various roadmapping theories, methodologies, and approaches.

As described in the literature review chapter, there is an absence of a standard and detailed process and approach for developing technology roadmaps and a lack of consistent methodologies. From the literature, numerous gaps and shortcomings have been identified in roadmapping procedures and processes, and traditional linear thinking methods' practices are still the order of the day (Kamtsiou *et al.*, 2014:25; Kamtsiou, 2016:106).

The weakness of the current approach of third generation roadmaps is the lack of an appropriate meso-level understanding which results in a disregard of critical meso-level drivers (Kamtsiou, 2016:106). Furthermore, according to Kerr and Phaal (2022:15) and others, there is a reluctance by organisations to fully appreciate the value of systemic and holistic practices being integrated into their roadmapping methodologies and processes (Saritas, 2013:117; Davoudi, 2015; Kerr and Phaal, 2022:15).

This weakness is typical of Hybrid based roadmaps that focus primarily on the 'what'. The critical shortcoming in this approach is the inability to make a direct connection between the current state and future state in terms of the 'what', 'how', 'why', and 'when' and is very much an inside-out perspective and, as such, may be inadequate for more long-term changes in the global marketplace (Cheng *et al.*, 2016:43; Kerr and Phaal, 2020:16).

The development of the conceptual framework will consider the environment holistically, through and by applying a systems perspective stance. Thus, the systemic technology roadmapping framework presents a novel organisational and multi-level systems perspective that sets out to design an agile, engaged, and aligned management approach in co-creating the roadmapping framework through the analysis of the views, perceptions and practices expressed by the focus group respondents.

The conceptual roadmapping framework is built on the following foundations:

1. A systems perspective, which is central to building an organisational ethos by providing a platform for adapting and responding to the dynamic business environment, thus allowing organisations to make measured technological decisions.
2. Underpinned by three critical elements; agility, engagement, and alignment.
3. Provides a means for trans-disciplinary learning through applying <sup>1</sup>co-innovation amongst groups by integrating multi-dimensional perspectives of complex systems and transition management theory into the technology roadmapping planning process. This is achieved through the application of a system analysis approach, where it is analysed both from an inside-out and outside-in perspective.

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<sup>1</sup> Co-Innovation enables organisations to work with its stakeholder (partners and customers) and to provide appropriate tangible and intangible assets from all collaborators necessary to co-invent and co-develop new innovations and designs (Saragih & Tan, 2018:377).

4. Developing a systemic view of the future technology environment based on an idealised planning and interactive approach (Ackoff *et al.*, 2012:35).
5. An intelligence-gathering, analytical, and time-based process used to create new knowledge for future technological advances.
6. Providing a mechanism for a temporal-spatial lens that is a structured visual chronology of an organisation's future strategic state (Kerr and Phaal, 2020:16; Kerr and Phaal, 2022:15; Farrukh *et al.*, 2014:62).

### **3.2 Theoretical grounding for the systemic technology roadmapping framework**

The technology roadmapping framework is built on three pillars that underline the notion of knowledge creation within a systemic environment, i.e. a world of technological advancement and change. The first pillar is the multi-dimensional perspective of complex systems, which enables an experiential learning journey for individuals within an organisation to grow into agile, aligned, and engaged managerial leaders. This enables individuals and organisations to co-create in a trans-disciplinary manner to achieve technologically robust innovative business solutions (Dessavre *et al.*, 2016:43; Kamtsiou, 2016:106).

The second pillar is related to transition management theory (TMT), which fundamentally views the world systemically in its approach to sustainable planning. Transition theory is about understanding the behaviour and dynamics of complex systems and sub-systems that are continuously interacting and adapting (Loorbach and Van der Lindt, 2007:21; Cheng *et al.*, 2016:43; Loorbach, 2017:626). Finally, the third pillar provides a mechanism for a temporal-spatial lens to create new knowledge for an organisation's future technological state (Ackoff *et al.*, 2012:35; Kerr and Phaal, 2022:15).

Due to the complexity of the present-day global environment, current technology roadmapping theory and approaches lack the ability to fully integrate the intricacies of the complexities of the ecosystem (Cheng *et al.*, 2016:43; Kamtsiou, 2016:106; Kerr and Phaal, 2017:277). This is particularly relevant with organisations in countries

where national policy uncertainty and markets are less integrated, which is, by its very nature, prominent in the underdeveloped regions of the world (Letaba *et al.*, 2017:15; Letaba, 2018:75).

### 3.2.1 *The multi-dimensional perspective of complex systems*

The exponential growth rate over the last decade in the convergence of technologies (Dyer *et al.*, 2011:154; Brinker and McLellan, 2020:4) and the lack of current technology roadmapping techniques necessitate the need to understand the system environment's complexities fully. As a result, numerous definitions are related to systems theory and complex systems (Bertalanffy, 1950:189; Ackoff, 1978:124; Churchman, 1971:227; Arnold and Wade, 2015:678; Senge, 2000:327; Dessavre *et al.*, 2016:43; Cabrera, 2021:1383).

General systems theory was first presented in the late 1940s by Ludwig von Bertalanffy (as cited by Rousseau, 2016:79) but has developed broader since its inception due to changing environmental and technological complexities that have confronted business today. It was a fundamental departure from traditional science, which dealt with cause-and-effect explanations.

As described by Ackoff, 'systems thinking views an organisation and its respective environment as a complex whole of interrelating, interdependent parts' (Ackoff, 1994:12). As indicated described by Ackoff (1994:12), a complex system is adaptive to input modifications within its operational environment. It is essential to note that the complex sub-systems within the system perform in a non-linear manner such that the modification undergone in the outcome is not at all proportional to the initial input.

Von Bertalanffy was well conversant in mathematical models which were applied at the time to describe physical systems. For example, Von Bertalanffy observed that living systems were naturally open as they had to interact with their environment, attracting and discharging energy to thrive (as cited by Rousseau, 2016:79). This is in sharp contrast to Newtonian models, which consider closed systems to describe

physical systems, such as the planetary system (Heylighen, Cilliers and Gershenson, 2006:124; Schneider *et al.*, 2017:208; Hossain *et al.*, 2020:23; Senge, 2000:327).

In systems theory, open systems impact the environment in a more complex manner, so its consequence can certainly not be ascertained or perfectly modelled (Heylighen *et al.*, 2006:124; Schneider *et al.*, 2017:208). Nevertheless, the notion of open systems suggests and brings to light several basic constructs that enable a better understanding of the term 'holism'. Each system has several environments delineated by a boundary with its own definitive identity. The flow of information and energy moves across the boundaries allowing the interconnectivity of different systems modelled (Heylighen *et al.*, 2006:124; Schneider *et al.*, 2017:208).

A key aspect of systems theory is that it considers the two-way directional concept of analysis, i.e., that of a downward direction related to reduction analysis and an upward direction of holism, as necessary when considering the nature of the system (Cilliers, 2005:267). As Cilliers (2005:267) discussed, systems thinking does not reject the value of the analytical approach. However, it complements it by utilising the integrative approach, where the system in the broader context is considered in terms of its relationship and interconnectivity with other systems. From an ontological perspective, it is clear that systems theory is very different from Newtonian theory in that the structure of reality is not based on material elements. However, it is grounded in abstract relationships between environments of complex systems (Valentinov *et al.*, 2019:300).

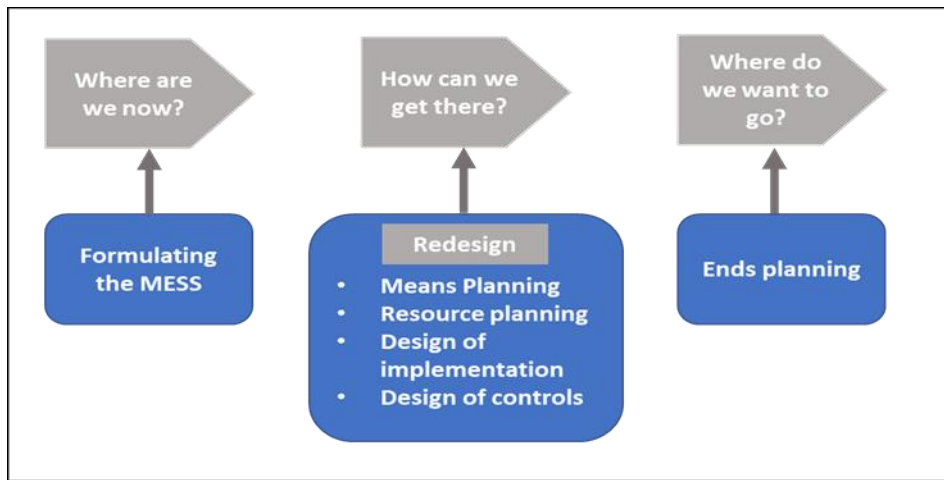
Ackoff (1999:177, 2012:35), a forerunner in systems thinking, operations research, and management science, developed the concept of idealised design through interactive planning from a systems thinking perspective. Ackoff defined three critical principles, participative, continuity, and holistic, in the interactive planning process. It was Ackoff's (2012:35) view that the process of planning is more important than the actual plan produced. The participative principle entails that all stakeholders should preferably contribute and participate in the various phases of the planning process in a co-innovative approach. The continuity principle states that planning is a perpetual process since the needs and desires of the organisation's stakeholders will vary over

time. Finally, the holistic principle focuses on the planning process at the systems levels, and the need to understand the interactions and connectivity at the various levels of the environment is paramount for the roadmap's success (Ackoff *et al.*, 2012:35).

The process of interactive planning comprises five phases (Figure 3.1) which can be viewed as systemic (Ackoff *et al.*, 2012:35):

1. System analysis comprises understanding the current reality (where are we now) and the critical obstructions hampering the organisation in moving forward and is defined as the MESS formulation.
2. Ends planning or idealised design (where do we want to go) is the unique attribute of Ackoff's (2012:35) approach and comprises developing a vision, specifying the design criteria, and then designing the system.
3. Means planning (how can we get there) which reviews current procedures, policies, and practices to ensure that they facilitate the organisation's move to the ideal future.
4. Resource planning focuses on understanding what is required from a financial, skills, technology, and facilities perspective to achieve the organisation's ideal future.
5. Design of implementation and controls is the final phase of the planning process, focusing on how the planned actions will be implemented (who, what, how, and when). It is a continuous monitoring approach to ensure that action plans have been achieved.

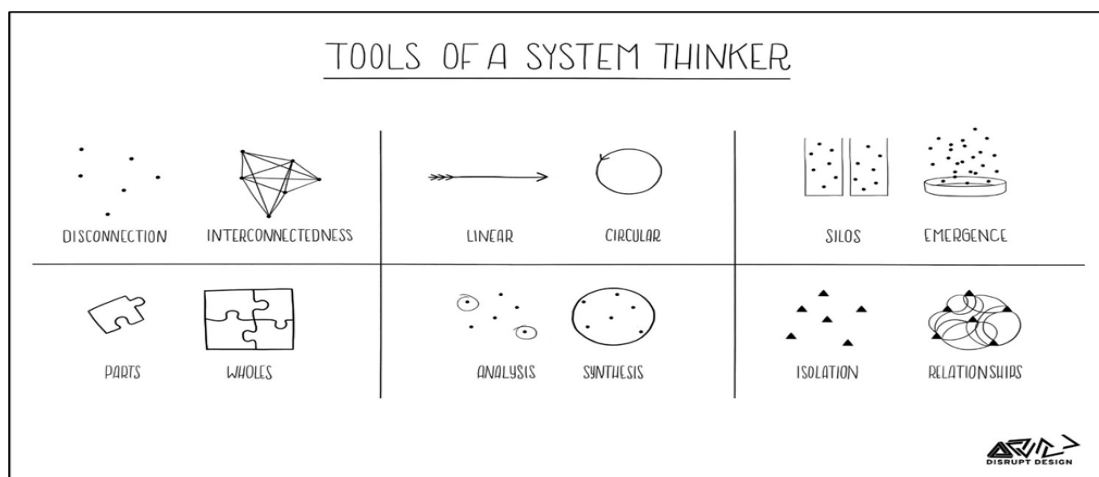
The interactive planning component thus follows a multi-directional systemic perspective for each time frame (current reality, short, medium and long-term) in that the various environments (operational, transactional, and contextual) are consistently undergoing analysis in identifying patterns, relationships, and risks from a technology complexity perspective. Within the interactive planning approach, the TIPS™ framework is constantly reviewed from an agility, alignment, and engagement perspective to attain the ideal future (Ackoff, 1999:177; Ackoff, 1970:8; Ackoff *et al.*, 2012:35).



**Figure 3.1: Interactive planning**

Source: Adapted from Ackoff et al. (2012:35)

Figure 3.2 simplistically depicts the difference in analytical concepts of a systemic thinker (holistic) and that of a reductionist thinker (linear) (Acaroglu, 2014). The linear thinker's prime approach in the analysis is to focus on the individual parts of the problem in seeking solutions, while a system thinker's approach is to analyse by way of understanding and exploring the interconnectivity, relationships, and synthesis of the parts in order to gain insight to a solution. In this study, the systems analysis approach formed a critical foundation for developing the emerging conceptual framework.

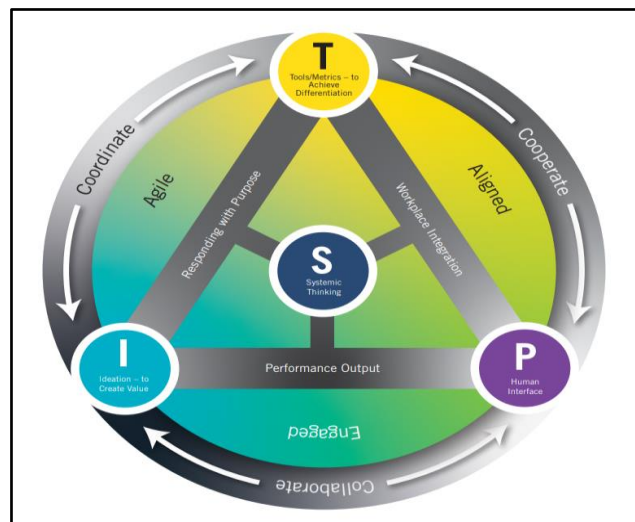


**Figure 3.2: Tools for the system thinker**

Source: Acaroglu (2014:2)

In a report published by Da Vinci Business School (2022:15), an organisational leadership framework is proposed to provide a holistic understanding for business leaders to integrate complex systems that impact organisations and society, as shown in Figure 3.3. The various layers of the framework offer a lens for discussion, reflection and co-innovation through systemic understanding throughout the system. The core of the TIPS™ framework has systems thinking as its foundation and the significant attributes of agility, engagement and alignment, which are essential contributions of multi-dimensional perspectives of complex systems.

The researcher submits that the TIPS™ framework is grounded within system thinking paradigm and when applied to the conceptual roadmapping framework process, could provide the means for trans-disciplinary learning and co-innovation within organisational communities in facilitating organisational, technological sustainability. Thus, the TIPS™ provides the rationale within the conceptual technology roadmapping framework for a more holistic and strategic decision-making process.



**Figure 3.3: Core elements of the TIPS™ Managerial Leadership Framework**

*T=Technology, P=People, I=Innovation and S=Systemic Thinking*

Source: Da Vinci Business School (2022:15)

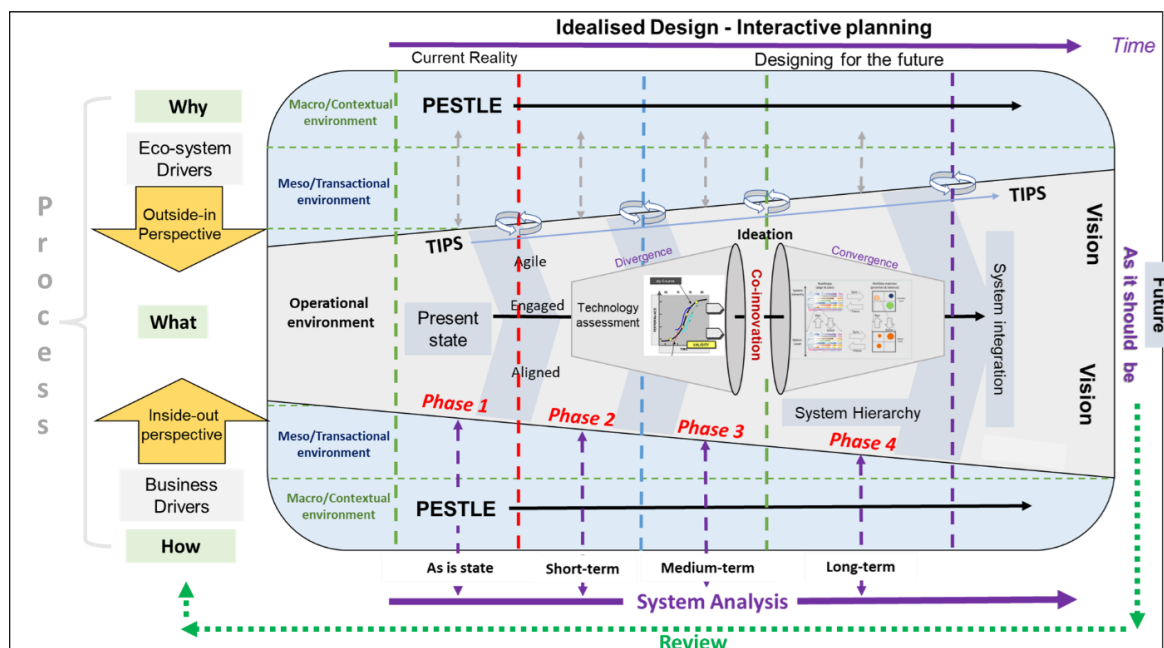
### 3.3 Proposed conceptual technology roadmap

Generally, current technology roadmaps are simplistic in their structure, and as such, have led to the wide-scale application of roadmapping techniques for long-term planning in organisations. Current technology roadmapping techniques are predominantly linear (reductionist) in their approach (inside-out singular perspective) (Phaal *et al.*, 2013:17; Loyarte *et al.*, 2015:486; Kamtsiou, 2016:106; Cheng *et al.*, 2016:43; Kerr and Phaal, 2020:16).

However, a detailed understanding of these complex dynamic systems is imperative for organisations to remain competitive (Arnold and Wade, 2015:677; Senge, 2000:327; Dessavre *et al.*, 2016:43; Cabrera, 2021:1383). The fast pace of technological and innovation development on organisational competitiveness is without question a key driver in organisational effectiveness and competitiveness. Nevertheless, a critical component of this competitiveness is the realisation that social complexity within the organisation system (micro, meso and macro environment) has a governing, regulatory, and controlling role on organisational stability, sustainability, and competitiveness. Thus, the need to move from the current technology roadmapping approach towards a new paradigm of understanding and mapping the complexities of our social, technological, and business environments is imperative (Arnold and Wade, 2015:678; Dessavre *et al.*, 2016:43; Senge, 2000:327; Cabrera, 2021:1383).

The conceptual technology roadmapping framework proposed for this study has been derived from the seminal work on systems theory from various authors (Ackoff, 1970:8, 1978:124,1999:177; Phaal *et al.*, 2013:17; Kerr and Phaal, 2014:8; Kerr and Phaal, 2022:15) for introducing the notion of a multi-layered temporal-spatial strategic lens in their governing roadmapping approach. The TMT theory, as described by Loorbach, Frantzeskaki and Avelino (2017:626) in their analysis of complex technology systems, and Cheng, Cheung and Fung (2016:43) in their proposed hybrid roadmapping approaches, where both the inside-out and outside-in perspectives are integrated. The TIPS™ framework, as described by the Da Vinci Business School (2022:15), is also considered a critical contribution to the development of the framework.

Figure 3.4 presents the conceptual framework, indicating the various components and techniques that will be applied in the technology roadmapping process. The rationale for this framework is that the components articulated in the conceptual framework follow a systems perspective as its foundation throughout the process (Kerr and Phaal, 2022:15). The roadmap is dynamic as it includes the time component, which is considered a critical factor in organisational competitiveness and sustainability. Kerr and Phaal (2022:15) pose three critical questions in their multi-layer roadmap; Where are we now? Where do we want to go? How can we get there? These questions posed by Kerr and Phaal (2022:15), are at the very heart of organisational planning.



**Figure 3.4: A conceptual technology roadmap**

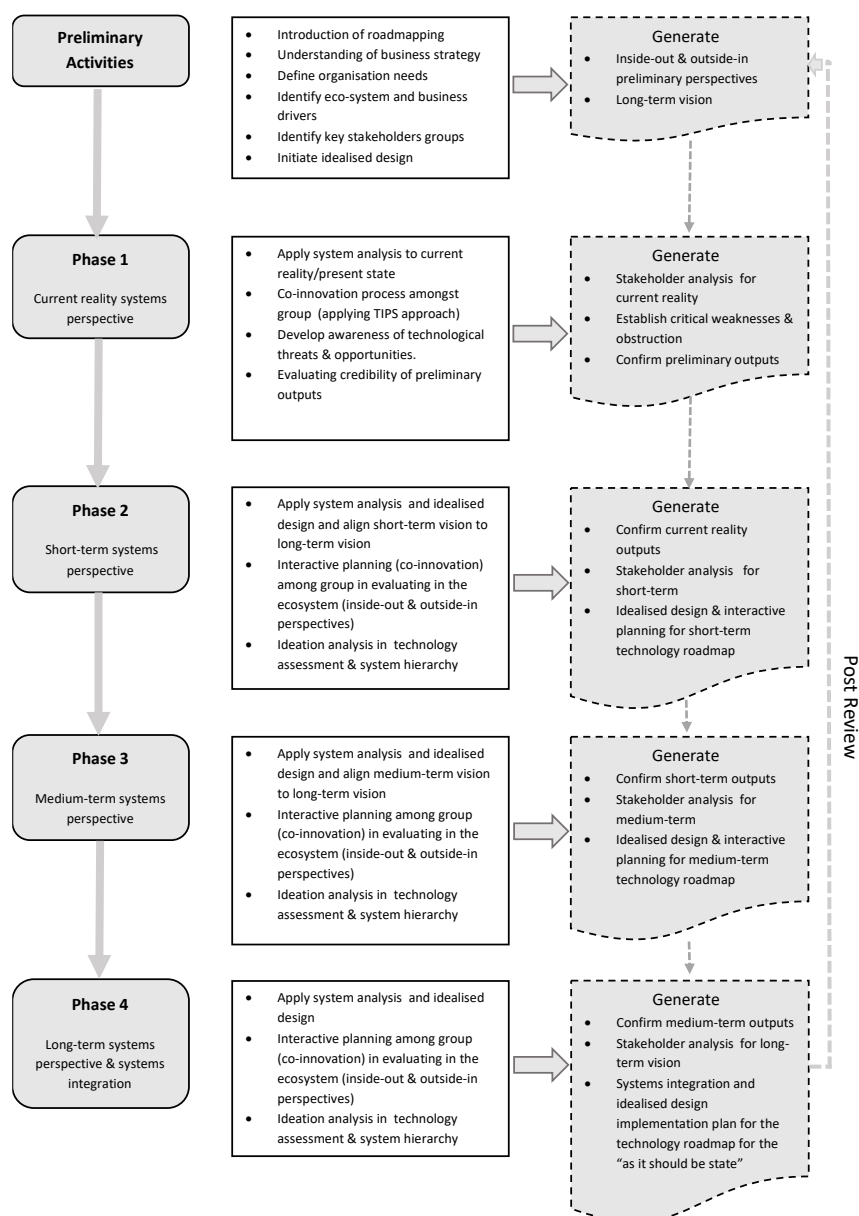
Source: Adapted from Kerr and Phaal, (2020:16)

### 3.4 Proposed roadmapping format and process

Figure 3.5 summarises the process of the conceptual roadmap framework. It is important to note that considerable analyses, discussions and workshops need to

occur before (preliminary activities), during and after the process to achieve a consolidated and robust outcome. Phaal, Farrukh and Probert (2004:374) cited that 'technology roadmaps are deceptively simple in terms of format, but their development poses significant challenges'.

The conceptual roadmapping process comprises five main steps: preliminary activities, current reality system analysis, short-term systems analysis, medium-term systems analysis and system integration and post-review (see next page).



### **Figure 3.5: Proposed conceptual technology roadmapping format and process**

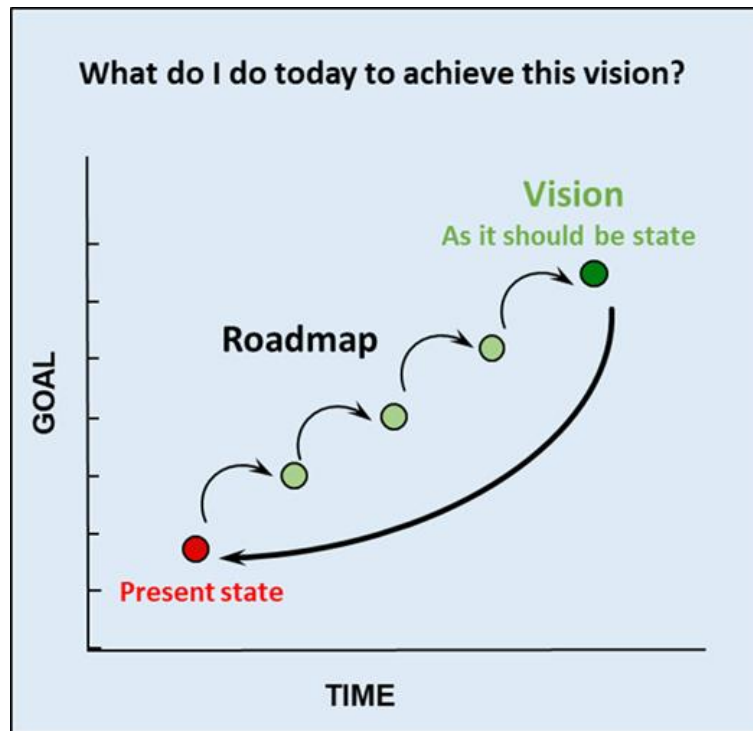
#### *3.4.1 Preliminary activities*

This phase of the process aims at understanding the organisation in terms of (a) defining the scope, boundary conditions and identification of key stakeholders, (b) needs and requirements of the existing strategy, (c) business and ecosystem driver landscape, and (d) initiating the idealised design process. The preliminary discussion aims to have a deep understanding of the organisation's requirement and sufficient need for the development technology roadmap. This entails a broad buy-in from stakeholders/participants, both from within and external to the organisation, into the process.

Once the preliminary drivers (business and ecosystem) have been identified with the participants, the idealised design process begins, and the roadmap's foundation is developed in terms of an end-state vision. Finally, a 'backcasting' approach is applied to the vision, which is central to an organisation's strategic approach to sustainable technology development.

'Back-casting' is a planning method in which a successful outcome is presumed for the future (a vision). The approach is to ask the question: 'what do we require to do today to reach that successful outcome?' As Ackoff, Magidson and Addison (2012) propose, this is far more effective than relying on forecasting, which tends to present a more restricted choice of options and thus could stifle creativity. An additional aspect of forecasting is that it tends to project today's problems into the future (Ackoff *et al.*, 2012:35; van Eck and Mennes, 2016:12).

Figure 3.6 shows the back-casting process where one begins with the end in mind, moves backwards to the present and then moves step by step towards the vision (Robinson, 2003:856; Ackoff *et al.*, 2012:35; Bowen and Forte, 2012:55; van Eck and Mennes, 2016:12).



**Figure 3.6: Backcasting approach**

Source: Adapted from Ackoff et al. (2012:35)

Once the vision has been clearly articulated, there is a high likelihood of consensus and a shared position of agreement among the participants (Cheng et al., 2016:43; Letaba, 2018:75).

### 3.4.2 Phase 1 - Current reality systems perspective

Upon completion of the preliminary activity phase, a current reality <sup>2</sup>systems analysis takes place. In this phase, the participants will consider and analyse the organisation's current state. The analysis is viewed from an inside-out and outside-in perspective and entails a detailed multi-directional system analysis of the current operational environment on the transactional and contextual environments (Cheng et al.,

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<sup>2</sup> Systems analysis is a holistic approach to analysis that focuses on the way that a system's constituent parts interrelate and how systems work over time and within the context of larger systems (Hossain et al., 2020:23).

2016:43). This allows the participants to co-innovate and co-create on critical technological positions related to existing organisational technology threats, weaknesses, obstructions and <sup>3</sup>wicked problems and opportunities. This is a crucial phase of the initial roadmapping analysis as without fully understanding the existing weaknesses, obstructions and wicked problems (MESS)<sup>4</sup> of the organisation's technological capability, one cannot plan effectively for the future (Ackoff *et al.*, 2012:35).

This phase also ensures that the engagement among the participants is aligned with a common purpose and understanding of the current state of affairs and the organisation's future vision. Throughout the process, the participants must continuously review and consider the preliminary activities' outputs in their thinking and adapt and realign.

### 3.4.3 Phase 2 – Short-term systems perspective

The initial approach applied in phase 2 is developing a short-term vision which is aligned with the long-term vision. First, the back-casting approach is applied to the short-term visioning process. Next, a system analysis is carried out where outputs of phase 1 are reviewed and considered in the analysis from an ecosystem perspective (inside-out and outside-in). Idealised design and interactive planning take the process further, where technology assessments and analysis are done among the participants in a co-innovation participative process (Ackoff *et al.*, 2012:35).

The technology assessment co-innovation process is primarily a divergent thinking method used to develop creative ideas through exploration. The process is free-

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<sup>3</sup> A wicked problem is a social or cultural problem that's difficult or impossible to solve because of its complex and interconnected nature. 'Wicked problems lack clarity in both their aims and solutions, and are subject to real-world constraints which hinder risk-free attempts to find a solution (Termeer, *et al.*, 2019).

<sup>4</sup> A MESS is a 'complex system of interacting problems including wicked problems.' You can't touch one problem without affecting the others. Deciding how to depict a problem system can involve a great deal of work (Ackoff *et al.*, 2012:35).

flowing and creative and is a non-linear approach. The application of the <sup>5</sup>S-curve is helpful in this phase as it indicates the rate of change of the technology through the various stages of a technology life cycle and when new and disruptive innovations (transition points) could enter the market (Loorbach and Van der Lindt, 2007:21).

The S-curve provides a deep understanding of the current and potential future technology trends, which are vital inputs into the roadmapping process and the competitive advantage of organisations (Letaba *et al.*, 2017:15; Loorbach, 2022:41). The system hierarchy phase is where technologies are ranked in a detailed manner in order of importance that meet the organisation's idealised state (vision). The thinking in this phase is predominantly convergent thinking, where technologies are graded according to established rules and logical reasoning using existing methods and approaches applying a priority matrix, options thinking, and other known methods. The output of this process is the development of a short-term technology roadmapping plan aligned with the organisation's long-term vision.

#### *3.4.4 Phase 3 – Medium-term systems perspective*

This phase follows the same analytical approach as in Phase 2, except that the analysis is focussed on the medium-term. An important aspect is that the medium-term vision must be aligned with the organisation's long-term vision. Short-term outputs are reviewed and adjusted accordingly, and the process of developing a medium-term vision is carried out. The technique of backcasting is applied, and detailed system analysis, idealised design and interactive planning are undertaken (Ackoff *et al.*, 2012:35). Finally, a technology assessment process is carried out, leading to the development of a medium-term technology roadmap.

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<sup>5</sup> The S-curve shows the technological progression over time which advances slowly at first, then accelerates and inevitably declines, forming an S-curve. The S-curve can be divided in 4 phases: emerging, growth, mature, declining (Taylor & Taylor, 2012:553).

#### 3.4.5 Phase 4 – Long-term systems perspective and systems integration

In the final phase, the analysis of the long-term vision, developed in the preliminary phase, is applied in a systems analysis which considers the ecosystem in terms of the long-term operational and ecosystem landscape (Ackoff *et al.*, 2012:35). It is followed by the technology assessment process for the final phase, where technology options for the long-term vision is proposed.

The crucial stage of this phase is when the participants integrate all the outputs in the roadmapping process by applying idealised design and interactive planning, forming part of the system integration analysis. It is a crucial stage in the roadmapping process, as it evaluates, reviews incorporates and adjusts all the outputs from the various phases into a detailed implementational technology roadmapping plan (idealised design plan).

Last but not least, in this phase, it is essential to note that in transition management theory, when considering complex systems, the implementation plan developed from the resulting technology roadmapping process requires a high degree of agility and flexibility to the changing ecosystem landscape (Loorbach *et al.*, 2017:626). However, more importantly, this agility and flexibility allow organisations to respond quickly to changes (both in timing and technology) as new data becomes available. Therefore, the technology roadmap must be seen as a living document and a continuous need for organisations to review, adapt and frequently update in all phases of the process to stay relevant and remain competitive.

### 3.5 Conclusion

The framework proposed in this chapter can be considered an appropriate methodology for technology roadmapping to address the system complexities organisations encounter regarding future technological competitiveness and sustainability. The conceptual technology framework is time-based, with linkages between various viewpoints that assist organisations in determining their current state, where they want to go, and how to get there. Furthermore, the conceptual framework

portrays quantitative and qualitative attributes of structural and temporal relationships and systems complexities among the various elements over time.

The various components are intricately linked within the boundaries of a complex and dynamic system that will continuously interact and react to a continuously evolving system driven by people, technology, and innovations. The conceptual framework is constantly impacted and driven by fluctuations in the operational, transactional, and contextual environments and the interconnectivity between and within them.

This systems approach of the conceptual framework could be counter-intuitive to the current reductionist linear approach of technology roadmapping and is based on a compressed market, product, and technological layer landscape (Kamtsiou, 2016:106; Letaba, 2018:75). Furthermore, the conceptual framework is based on the assimilation of theories, as described in this chapter, and they take the form of continuous integration, interconnectivity, and feedback loops of sub-systems within the framework of system complexity. Thus, the framework components are multi-functional both in the vertical and horizontal planes and interact in a non-linear manner.

The proposed conceptual framework provides an interactive and systems approach to the technological landscape and complex systems' social interconnectivity. It is proposed that it could lay the solid foundation for organisations for an alternative, more robust and realistic systems approach to technology roadmapping.

## CHAPTER 4

### RESEARCH DESIGN AND METHODOLOGY

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#### 4.1 Introduction

The research design methodology developed and applied for this research study sought to answer the primary research question posed in this study. The main research question was concerned with the limitations of the current approaches to roadmapping and prompted the design of a unique alternative conceptual framework for technology roadmapping that is capable of considering the environment systemically. The principal research question is:

*What is the nature of a technology roadmapping framework that is responsive to an electricity utility's environment where the rate of technological adaptations and changes outpace business processes?*

This chapter is informed and based on the theoretical and conceptual frameworks developed and described in the preceding sections. It describes the approach undertaken and adopted by the researcher in the research design phase. It then further explains the reasoning for the methodology regarding sampling techniques, data acquisition, and data analysis. The chapter then concludes with a review of the ethical considerations and limitations of the study.

#### 4.2 Research design

The form of research philosophy applied in this study directly impacts and influences the selection of the research approach and strategy considered. The research philosophy, in turn, was affected by the availability and type of data that was accessible to the researcher. This section describes how the research was systematically undertaken and applied accepted research methodologies to reach reasonable and rational conclusions.

#### *4.2.1 Research philosophy and approach*

From the literature, research methodologists' approach to a specific research philosophy often reveals and reflects the researcher's rational view of the design arrangement (Bambale, 2014:879; Creswell and Plano Clark, 2017:23). There are four known research philosophical stances; positivism, interpretivism, realism (Creswell and Creswell, 2018:151) and pragmatism (Morgan, 2014:1053; Dewey, 2008/1925b:372).

Few social scientists would describe themselves as a positivist, interpretivist, or realist as these terms are used mostly by methodologists and theorists. They define the theoretical assumptions which underlie different approaches to research (Hibberd, 2014:186). There are many diverse views in sociology about what societies are and what the best ways are of obtaining knowledge of them (Bryman, 2012:7135; Creswell and Creswell, 2018:151).

Positivism is commonly used to stand for the epistemological assumption that empirical knowledge is based on the principle of objectivity, verification, and reproducibility and is the foundation of all authentic knowledge (Bryman, 2004:769; Hanzel, 2010:84). The critical principle of positivist research is based on the premise that the researcher is detached from the phenomenon that is being investigated in terms of objectivity (Coghlan and Brannick, 2014:55).

It is the researcher's view that the positivist approach and perspective was neither suitable nor appropriate in the exploration of developing a conceptual framework for technology roadmapping within complex social systems. Technological and innovation development is a non-linear, complex process within a complex system and often occurs along multiple pathways. An example of this would be that a successful technological strategy applied in an organisation in a country can give different outcomes if applied elsewhere (Ghinoi, 2016:135).

The framework proposed for the development of a conceptual technology roadmap also integrates critical issues such as multidimensional and complex systems theory

and transformational technological transitions. Thus, the application of systems thinking and the understanding of complexities, relationships, and interactions of the components of the system and/or on organisational thinking is crucial in the eventual development of a technology roadmap (Churchman, 1968:45; Kamtsiou, 2016:106). Furthermore, the repeatability of technology roadmapping frameworks is not the norm, as shown by the inherent differences described in the literature and is dependent on the context of the area being mapped (Radnor and Probert, 2004:27; Albright and Kappel, 2003:40; Farrukh *et al.*, 2014:62; Phaal *et al.*, 2001:374).

Thus, the philosophy adopted for this research was subjectivist and pragmatist due to the systemic and complex nature of technology roadmapping. According to Saunders *et al.* (2009:14) pragmatism is defined as,

*...a position that argues that the most important factor of the research philosophy adopted is the research question...arguing that it is possible to work within both a positivist and interpretivist paradigm.*

It applies a practical approach to the integration of different perspectives to help create, assemble, and interpret data. According to Powell and DiMaggio (1991:235), a pragmatist's requirement is to facilitate human problem-solving and is not about the science of discovering the definitive truth, as both reality and truth are continually changing and evolving. Thus, the researcher's approach to best answer the research question was to employ a pragmatic stance through the application of systems thinking in terms of gaining new knowledge.

#### *4.2.2 Research methodology*

A mixed method qualitative approach could include both an interpretivist approach of systemic understanding and a positivist approach of reductionist data analysis in obtaining complementary information. In combining both qualitative and quantitative data collection methods, the researcher was able to better understand and contextualise critical aspects of this study (Creswell, 2015:180; Creswell and Creswell, 2018:151).

The application of a mixed method approach installed a sequence of inductive-deductive research processes and had the ability to reveal both a convergence and divergence of data, contradictions, and inconsistencies which provided significant in revealing new knowledge (Teddlie and Tashakkori, 2009:18). There are several theoretical differences or variations among qualitatively driven mixed method approaches, and numerous theorists have characterised these in various ways (Denzin and Lincoln, 2000:201; Hesse-Biber *et al.*, 2015:21).

The researcher's approach was based on the objective stance, which accepts that social reality is at times subjective and encompass stories or senses constructed or co-constructed by people and others within a specific community. Thus, the data provided a rich understanding which enabled meaning-making in terms of interpreting the constructs.

### **4.3 Population and sampling**

The population of a study is understood as the total number of contributors that meet the attributes to participate in the study (Robinson, 2003:856). In this study, the target population consisted of senior executives and research and development technologists from global electricity companies. The members of this association are recognised as specialists in their understanding of technology research and technology roadmapping development within their organisations.

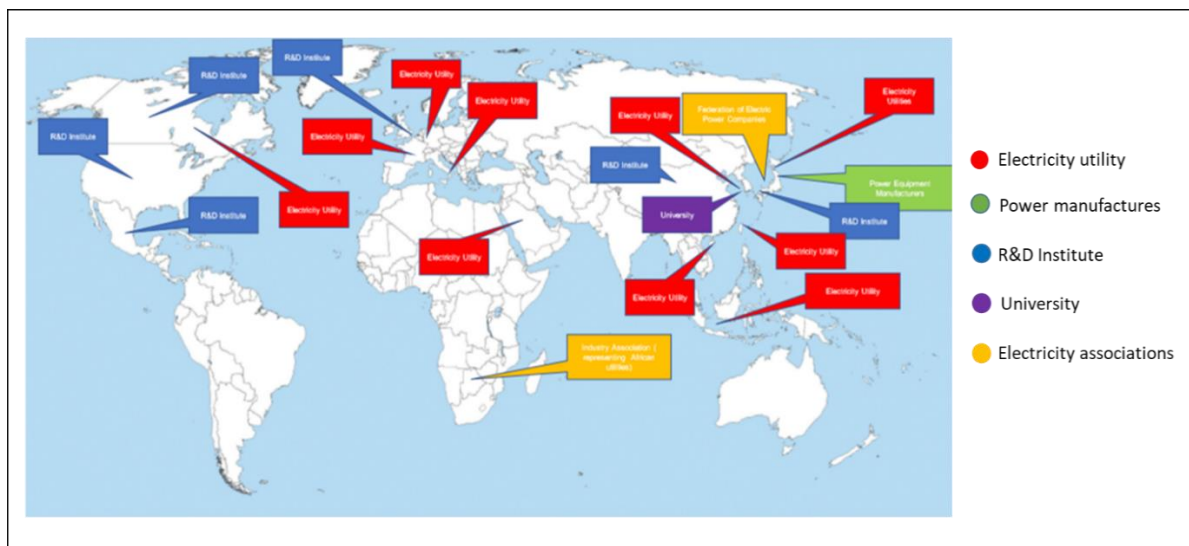
The researcher applied maximum variation sampling, which is a purposeful sampling strategy. This selection was chosen to ensure that the participants were culturally different and from various parts of the world and subsequently reflected the diversity of the participants relevant to the research question (Creswell and Creswell, 2018:151). According to Creswell and Plano Clark (2017:23),

*The central idea that participants are purposefully chosen to be different in the first place, then their views will reflect this difference and provide a good qualitative study with a complex picture of the study.*

Patton (2002:246) further describes purposive sampling as an approach to intentionally select information-rich datasets and samples for gaining insightfulness and a comprehensive understanding of the study at hand.

The literature (Creswell, 2003:37; Creswell and Plano Clark, 2017:23; Creswell and Creswell, 2018:151; Maxwell, 2012:162; Brannen, 2005:184; Bryman, 2012:134) reveal that different sample sizes for qualitative mixed method studies vary from 20 to 30. The sample sizes are variable because saturation points will be reached at different points of data collection and analysis. The idea of saturation is where one stops collecting data when congestion occurs, i.e. where the gathering of additional data no longer becomes meaningful (Charmaz, 2006:97).

Figure 4.1 illustrates the approach adopted in the study in terms of the purposeful maximum variation sampling applied. What can be seen from the figure is that the selection was to ensure that the participants were from different parts of the world that reflected their cultural diversity, and which subsequently reflected differences and differentiated views and perceptions of the participants.



**Figure 4.1: The potential global respondents**

Based on the above, the researcher followed a purposive sampling approach involving 16 and 25 participants for the Brussels and Berlin respectively for focus group

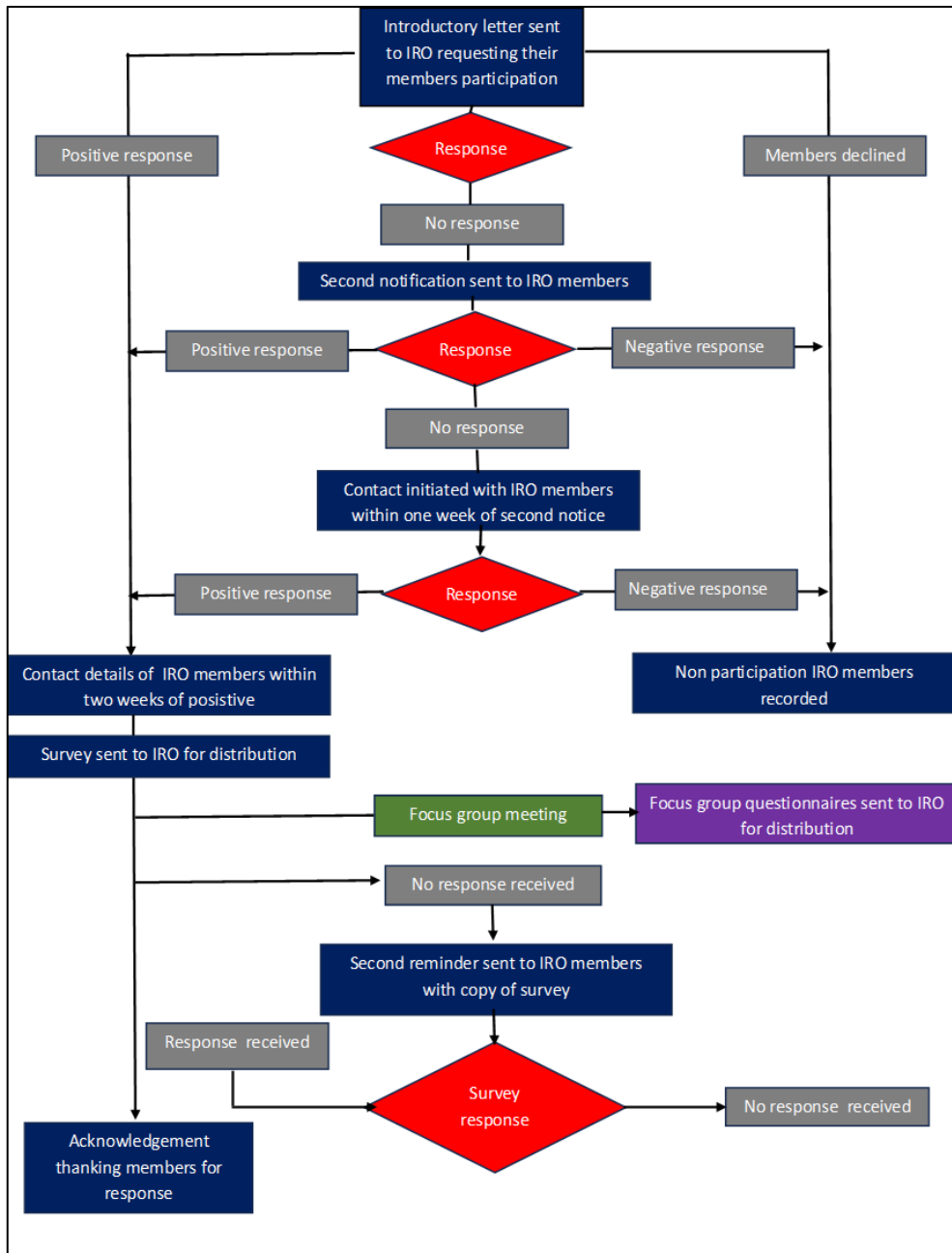
meetings, and 16 and 25 participants for quantitative on-line surveys. As mentioned earlier, the strategy used to facilitate access to the respondents was through an international industry association where the respondents and participants were members. It is important to note that not all the same participants (approximately 10%) attended the semi-structured workshops over the study period.

This section describes aspects pertaining to the sampling procedures and questionnaire design for the primary data (qualitative and quantitative). It also addresses the approach in the collection of secondary data and analysis.

#### *4.3.1 Data collection and analysis*

The process shown in Figure 4.2 of the administration procedure indicates that the initial correspondence with the prospective organisation was conducted via e-mail. The correspondence included a solicitation and an introductory letter from the researcher. Non-responsive member organisations were contacted via e-mail in order to facilitate their inclusion in both the surveys and workshops.

Questionnaires were forwarded to the International Research Organisation (IRO) four weeks before the planned workshops for distribution to their members. All surveys, questionnaires and documents related to the outputs of the workshop were documented and kept in an Excel file and MSWord format.



**Figure 4.2: Data collection process map**

Creswell and Plano Clark (2007:59) suggest that mixed method research is useful for assessing whether there are converging or diverging views from different data collection strategies, and through the process, new inferences can be made. The study lay within the interpretivist mixed method approach, where qualitative methods were given priority over quantitative methods. This resulted in a rich and complementary dataset for the process of theory development.

The researcher believed that the introduction of a mixed method research approach had increased the understanding of the role of human nature in the context of social reality within large corporate entities. Thus, by not exclusively depending on a single research methodology or approach, the rationality and credibility of the research results are enhanced (Denzin, 1978:201; Holtzhausen, 2001:18; Patton, 1990:137; Creswell, 2003:37; Creswell, 2014:201; Creswell, 2015:180; Creswell and Creswell, 2018). It can therefore be inferred that a mixed method method design approach can expand the understanding of the study in terms of the insight into human nature from a systems perspective. The study relied on a concurrent mixed method design, utilising triangulation to verify and analyse solutions to the phenomena studied.

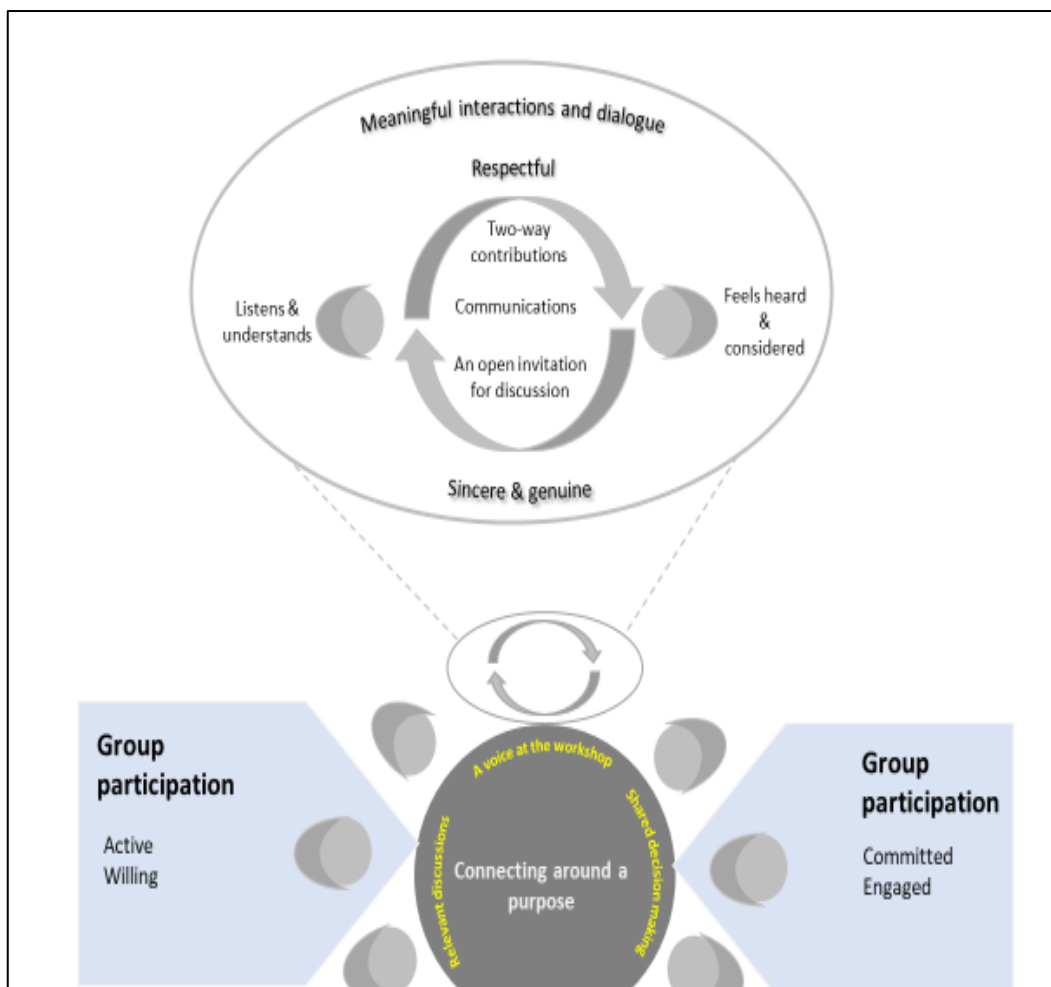
As described earlier, the intent was to collect data through focused but semi-structured workshops with groups of individuals based on a maximal variation sampling approach (Creswell and Creswell, 2018:151). As described in Chapter 1, focus group, also known as a group interviews as described by Gibbs (2012:31), is defined as an organised interactive dialogue session with selected groups of individuals to gain opinions on a research topic.

The data collection process was a systematic process of scrutinising and ordering information acquired from semi-structured workshops and other material collected during the focus group discussions (Jacob and Furgerson, 2012:10). The objective of the workshops was to facilitate an approach to open discussions and thinking on what the key technology drivers and environmental factors are that lead to the development of organisational technology roadmaps and strategies in an electricity utility. The questions and forms of enquiry were designed to test and examine this objective, for example:

1. What are the main strategic factors that are positively influencing your approach to technology roadmapping outcomes?
2. What was the main focus for undertaking a technology roadmapping exercise?
3. What is the primary usage for these technology roadmaps?
4. What is the planning horizon for your technology roadmaps?

According to Jacob and Furgerson (2012) an interpretivist researcher should limit the number of questions posed, as this would allow for the free flow of discussion and information sharing as well as the emergence of surprising and unpredicted data and responses from participants. Thus, the questions were semi-structured, and the approach adopted was what Jacob and Furgerson (2012:10) recommend in terms of an invitation to the group.

The phrase the researcher took was ‘what can you tell me about this?’ This was both an invitation and a non-threatening expression to an open-ended question which is appropriate for an exploratory enquiry. Figure 4.3 shows the processes of the workshop designed in terms of the researcher’s approach.

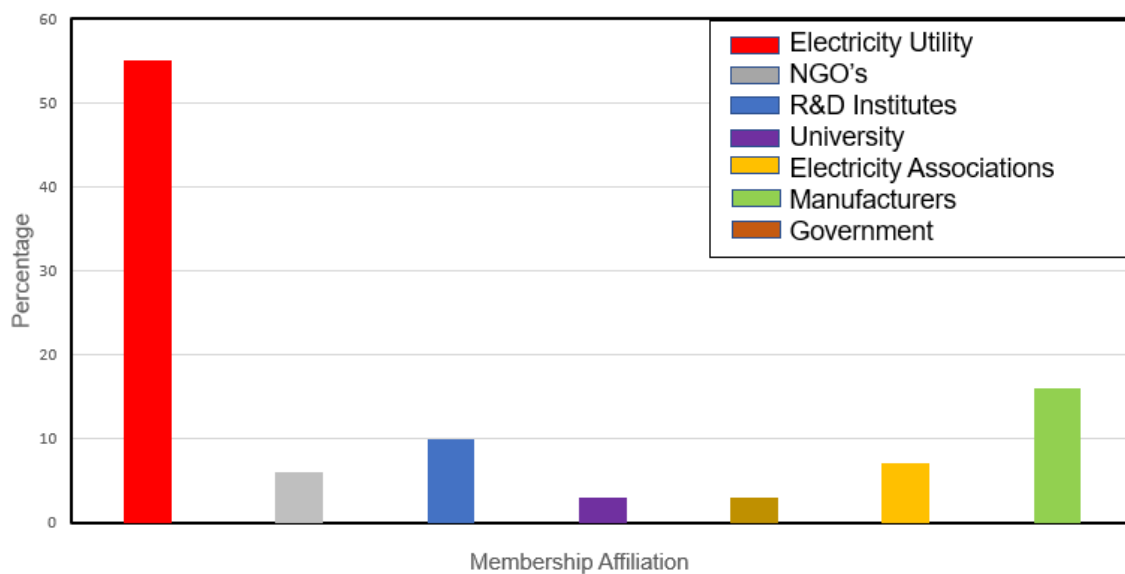


**Figure 4.3: Process of workshop engagement**

*Source: Adapted from Nowell, Norris, White and Moules (2017:8)*

Two workshops were held in different parts of the world over a three-year period. Figure 4.4 further unpacks the participants into organisational areas. Electricity utilities made up 55% of the participants, followed by electricity manufacturers (15%), research and development organisations (10%), electricity associations (6%), and NGOs, universities and government all less than 5%.

A final focus group workshop was arranged and planned for the IRO members for May 2021. However, in the first quarter of 2020 the global pandemic of COVID-19 caused lockdowns around the world which had a major impact globally thus resulting in the cancellation of the workshop. As a result of the global lockdown, the researcher then applied an alternative approach in the form of a survey questionnaire which was distributed to the IRO members towards the end of 2020.



**Figure 4.4: Industry membership affiliations**

Tables 4.1 and 4.2 summarise the member participation and include the membership affiliations. What is notable was the dominance of electricity companies and electricity research institutes (>75%) from Europe, Asia, Africa and Central and North America. However, this finding is not surprising, seeing that the IRO membership is predominantly made up of global electricity, research, and manufacturing companies.

**Table 4.1: Sector members at the Brussels workshop**

Sectors of Member participation	Number of Attendance	% of Total Participants	Country Composition
Electricity Research Institutes	7	43.7	China, Japan and Mexico and Belgium
Electricity Power Utilities	5	31.3	Japan, France, South Africa and Canada
NGO's	2	12.5	Japan
Electricity Manufacturers	2	12.5	USA
All Sectors	16	100	

**Table 4.2: Sector members at the Berlin workshop**

Sectors of Member participation	Number of Attendance	% of Total Participants	Country Composition
Electricity Research Institutes	8	32	China, Germany, Japan, USA, Mexico
Electricity Power Utility	15	60	China, Hong Kong, France, Italy, Canada, RSA, Turkey, Germany
Universities	1	4	Netherlands
NGO's	1	4	Japan
All Sectors	25	100	

The data collection and analysis approach shown in Table 4.3 was a systematic process of scrutinising and ordering information acquired from the semi-structured workshops. During the focus group discussions, additional material was collected, such as reports and presentations on technology strategies from member organisations. The researcher documented and kept all documents related to the outputs of the workshops.

**Table 4.3: Data collection and analysis**

Type of data to be collected	Data approach
Primary qualitative data (semi-structured workshops). Workshops carried out over a 3-year period.  A qualitative survey questionnaire was carried out.	Thematic analysis (method of analysing data in terms of semi-structured workshops). The researcher carefully examined the data to identify common themes, topics, ideas and patterns of meaning (Maguire and Delahunt, 2017).
Data type	Analytical approach
Primary qualitative data (Semi-structured focussed workshops) and survey questionnaire.  Secondary qualitative data	Comparative analysis by seeking explanations for similarities and differences that exist between datasets by way of triangulation/convergent analysis (Creswell and Creswell, 2018:151). The data collection process used a systematic process of scrutinising and ordering information acquired from semi-structured open-ended workshops and survey questionnaire.  Secondary qualitative data collection (where appropriate) was undertaken to enhance the triangulation analysis.

The qualitative topics/questions were designed to probe into critical issues related to organisational strategy technology choice, and the application of technology roadmapping in considering key technology outcomes, for example:

1. How did you come to select the technology, and what were the key drivers in your choice?
2. Are the technology roadmaps integrated across various divisions across your organisation?

Topics were sent to the IRO for distribution to the members four weeks in advance of the workshop for them to familiarise themselves with what was required. Table 4.4 shows a sample of questions posed. The duration of the focus group sessions was over a one-day period.

**Table 4.4: An abridged example of survey questions**

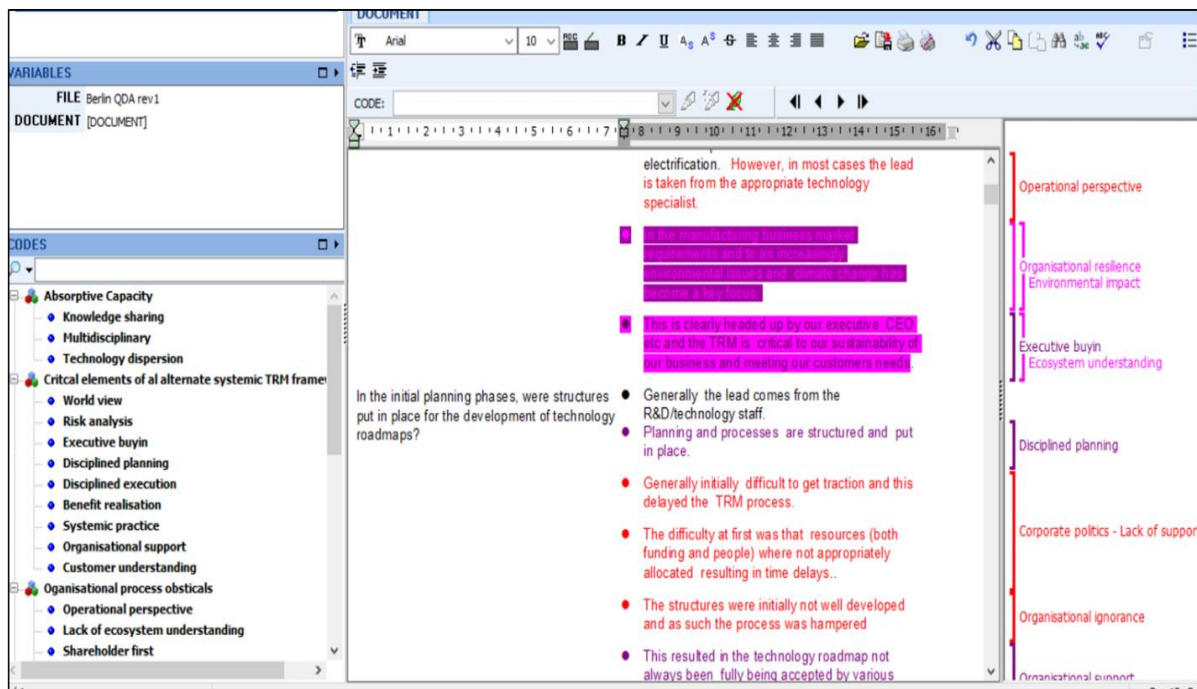
Questions	Response
<b>Technology Roadmap development process</b>	
1. Who sponsored the development of TRM?	
2. In the initial planning phases, were structures put in place for the development of technology roadmaps?	
3. To what degree did the sponsor/s have a significant impact on the methodology applied during the TRM development?	
4. In the TRM analysis, did you apply an exploratory or normative approach and if so, how was the approach adopted?	
5. What were the main strategic factors that influenced the approach to technology roadmapping outcomes in your organisation?	
6. In the TRM process that you participated in, how important were the operational drivers that influenced the analysis?	

The approach adopted in this research was to utilise qualitative data analysis software as a beneficial tool for the process. This was based on literature that proposes that when dealing with qualitative data, it provides the ability to manage and handle large amounts of textual data sets in terms of speed, improvements of rigour, and relative ease of navigation (Drisko, 2013).

After a review of current software systems, the researcher selected QDA Minor Lite software to analyse the qualitative data that were collected (van der Walt *et al.*, 2020:34). The primary advantage of using the software is the robustness and speed in terms of data processing, thus allowing the researcher more time to focus on analytical, conceptual, and robust research and data analysis.

QDA Miner is a qualitative software package for coding textual and graphical data. It can annotate, retrieve, and review coded data, documents, and images. The programme has the process ability to manage multifaceted projects involving large numbers of documents. QDA Miner also provides several investigative tools that detect patterns in coding and interactions between codes and numerical or categorical properties (Table 4.5). Finally, it is the researcher's view that the use of an electronic

software system should ensure impartiality during the analytical process of data, thus adding to the trustworthiness and objectivity of the analysis process.



**Table 4.5: Example of QDA Miner coding and categories.**

#### 4.3.2 Quantitative collection and analysis

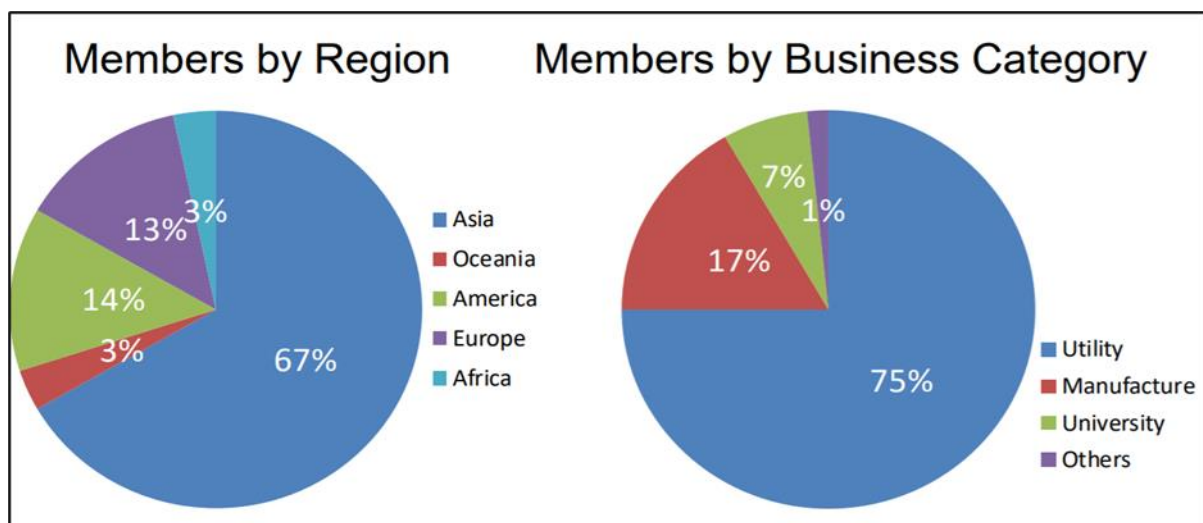
This section explains the issues related to sampling, questionnaire design, and the administration of the process of sampling for quantitative data collection. The quantitative surveys were directed to address the research questions of this study which was informed by the literature review and the proposed conceptual framework.

Quantitative surveys were undertaken with the IRO members with a potential sample size of 63 respondents. As discussed earlier, a purposeful sampling strategy was employed with the primary aim of obtaining feedback and critique on crucial technology drivers and technologies from individual experts outside the workshop environment.

The questions posed in the survey included aspects related to technological drivers, environmental drivers, emerging technologies, business drivers, and organisational

approaches to technology roadmapping. The researcher considered these critical elements in the understanding of corporate decision-making in the rollout of technology strategies.

What was prominent was the large number of responses from the Asian region, and specifically Japan. This was expected as the IRO was initially founded in 1968 as a Japanese-only research association. Since 1995, and after a review of its strategic intent, it has become a global organisation with an international membership, as can be seen in Figure 4.5. The quantitative surveys were designed to ensure that it was easy to complete by the members and to reflect the essential attributes of the research questions.



**Figure 4.5: Membership by region and category**

The questions marked with an asterisk were made compulsory to complete, an example of which is shown in Table 4.7. Creswell (2015:181) suggest that a well-designed quantitative survey should be simple, acceptable to respondents, and appropriate for the intended study.

The quantitative study was conducted in parallel with the qualitative study over the study period. In addition, secondary quantitative data was utilised to enrich the study in terms of the overall research objectives. The secondary data sourced relevant to the research study.

**Table 4.6: Example of compulsory questions**

1. Have you ever participated in a technology roadmapping (TRM) process for your organisations?
2. Do you have experience in technology roadmapping (TRM) in terms of future technology requirements(>10yrs)?
3. How long have you been involved in technology roadmapping activities?
4. Where did you contribute and participate, and what was your role in the technology roadmapping exercise?
5. What was the planning horizon (in years) for your organisation's technology roadmaps?
6. In the technology roadmap process, what was the primary motivation for undertaking the exercise?

The data collection and analytical approach for the quantitative data is shown in Table 4.8. Also, a descriptive statistical analysis, where possible, was conducted on auxiliary quantitative datasets obtained from the IRO member surveys and annual organisational reports.

**Table 4.7: Data analysis**

Type of data to be collected	Data approach
Primary quantitative data (surveys directed to IRO members).  Secondary data collection.	Surveys directed to the IRO members.  Secondary data where appropriate was sourced from journal reviews, company annual reports and official statistics.

Data type	Analytical approach
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Primary quantitative data	Descriptive statistics analysis of the quantitative data was undertaken.
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#### 4.4 Data integrity

The notion of trustworthiness in qualitative research within the positivist community has often been doubted due to their view of the concepts of validity and reliability (Silverman, 2001:161). However, those arguments no longer hold water as the overarching issue is how researchers attempt to deal with the issues of academic rigour and research integrity.

Guba (1981) proposes an alternate method for validity and rigour by considering four criteria which he suggests that qualitative researchers could follow in the quest for trustworthiness. However, from Guba's (1981) original conceptualisation of qualitative trustworthiness, more has been done, and continues to be done (Nowell *et al.*, 2017:13; Tracy, 2010; Gray, 2018:213).

In the development of these criteria, Guba (1981) is aware that the constructs proposed run parallel with the criteria applied by the positivist researcher, namely:

1. Credibility (instead of internal validity).
2. Transferability (instead of external validity/generalisability).
3. Dependability (instead of reliability).
4. Confirmability (instead of objectivity).

It is important to note that the concepts developed and proposed by Guba (1981:91) have been accepted by many qualitative researchers over the last decade (Shenton, 2004:75).

#### 4.4.1 *Trustworthiness*

Mixed method approaches also tend to increase the reliability and integrity of a study in several ways. According to Gray (2018:213) and Shenton (2004:75) the use of different data sets increases transferability and dependability in terms of providing a wide range of diverse perspectives. In addition, confirmability is improved through the use of both secondary and primary data, which reduces researcher bias (Gray, 2018:213; Shenton, 2004:75).

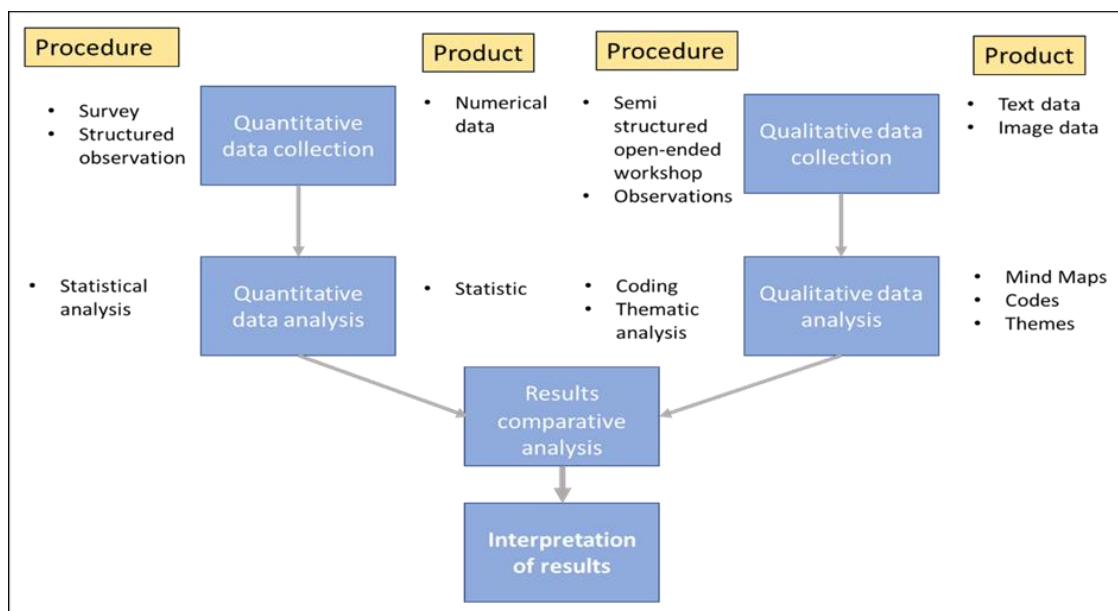
A data triangulation approach suggests the collection of information (both qualitative and quantitative) from varying participants of different backgrounds (Creswell and Creswell, 2018:151), and then compared with another source, such as the literature or conceptual frameworks (Jack and Raturi, 2006:357; Gray, 2018:213) or another set of data. In this approach, it requires a consistent review of specific data from various sources from structured or semi-structured interviews and from quantitative data from the relevant questionnaires and secondary data.

Thus, the triangulation methodology requires combining sets of data collection methods (qualitative, quantitative and secondary) into a form of comparative examination of the data and one where the interpretation of the results leads to an outcome. A secondary qualitative and quantitative document analysis was carried out from publicly available technology roadmap articles. The integration of the secondary data with the primary data was a beneficial approach to improve the validity of the results during the triangulation process (Jack and Raturi, 2006:357; Gray, 2018:213).

Figure 4.6 provides a summary of the procedural steps which were utilised to carry out the parallel exploratory research typology of the study. The first procedural step of the initial phase included the collection, in parallel, of qualitative data and observations by way of semi-structured workshops and a survey questionnaire, quantitative data by developing specific questionnaires for purposeful sampling, and secondary data by means of publicly obtained reports and documents.

The second procedural step was the collection and analysis of the data in terms of coding and thematic analysis, descriptive analysis, and data imagining of the qualitative, quantitative, and secondary data, respectively. The final and third procedural step was the interpretation, by applying triangulation to the qualitative, quantitative, and secondary results. This approach of triangulation further added insight into the overall analysis in terms of the study's purpose, aim, and objectives.

Thus, the rationale for selecting a mixed method triangulation research paradigm from a pragmatic perspective was based on the fundamental premise of understanding socially constructed meanings of reality from individuals and groups which then lead, through observations and meaning-making, to the generation of theory. The researcher thus established the mixed method three-phased research approach that uncovered meaning through observations and induced understanding (Creswell and Creswell, 2018:151).



**Figure 4.6: Parallel mixed method design**

Source: Adapted from Creswell and Plano Clark (2007:59)

#### 4.4.2 *Credibility*

Credibility is a critical criterion which the positivist researcher addresses as that of internal validity. Internal validity ensures that the research study undertaken conforms to the measures and procedures required and is appropriate for what is intended for the study (Guba and Lincoln, 2005:191; Stahl and King, 2020:30).

The following approach has been adopted by the researcher in ensuring credibility and confidence in the dataset; the researcher followed Dervin's (1976:27) information-seeking approach during the workshop (focus group) sessions. This was particularly relevant in terms of the time allocated for reflection and discussion on the questions posed during the sessions (Dervin, 1976:27; Lincoln and Guba, 1985:129; Teddlie and Tashakkori, 2009:18; Gray, 2018:213 Stahl and King, 2020:30). The researcher invited participants to reflect on the questions posed in terms of the context and understanding of the study.

Furthermore, within the confines of credibility, Guba (1981:91) discusses the concept of 'prolonged engagement' between the researcher and the participants for both to establish a relationship of trust and adequate understanding between the parties (Guba, 1981:91). Concerning the aspect of 'prolonged engagement' as described in Chapter 1, the researcher has been involved with the organisation for the last 20 years as a board member and is currently sitting as the Chairman Emeritus of the Board. Thus, by example, the researcher believes that his trust, understanding, and relationships within the organisation and its members are well entrenched.

However, the researcher was also aware of the dangers of prolonged engagements, as described by Lincoln and Guba (1985:129) and Silverman (2001:161). The threat of being absorbed in the culture and ethos of the organisation can impact the researcher's professional judgement and thus influence the findings of the study (Lincoln and Guba, 1985:129; Silverman, 2001:161). For that reason the study employed a mixed method triangulation of data collection and used a combination of parallel qualitative and quantitative approaches (Creswell and Plano Clark, 2017;

Creswell and Creswell, 2018:151; Creswell, 2015:180; Gray, 2018:213; Teddlie and Tashakkori, 2009:18; Stahl and King, 2020:30).

As discussed earlier, mixed method triangulation approaches increase the reliability and integrity of a study, according to Gray (2018:213) and Shenton (2004:75). The use of different data sets increases transferability and dependability in terms of providing a wide range of diverse perspectives. In addition, confirmability is improved through the use of both secondary and primary data, which reduces researcher partiality (Gray, 2018:213; Shenton, 2004:75).

Based on Maxwell's (2009:149) seven-point checklist in combatting the threats to both internal and external validity (trustworthiness and credibility, respectively), he proposes the following:

1. Intensive long-term field study – in-depth awareness of the field situations.
2. Rich data – utilising detailed and varied data (qualitative and quantitative).
3. Respondent validation – obtaining feedback from participants in order to minimise any misconception of their views.
4. Search for discrepant evidence by testing opposing views.
5. Triangulation – collecting converging evidence from different sources.
6. Quasi statistics – using definite numbers instead of adjectives.
7. Comparison – comparing data sets across different focus sessions.

The above checklist was applied as a guideline to ensure an increase in trustworthiness and credibility. To ensure improved credibility, as proposed by Guba and Lincoln (2005:191), the researcher used member checking relating to the accuracy of data during and after each session. This was done by ensuring that after each workshop session, time was allocated to review the critical outputs of the workshop. Also, detailed outputs of the workshop's open-ended discussions were forwarded to the IRO secretarial office for distribution to its members for comments, review, and feedback.

#### 4.4.3 *Transferability*

Transferability is concerned with the replication of findings in that the results of the study can be applied to other situations (Merriam, 1998:25). Within a qualitative study, in many cases and due to their sample size, it is almost impossible to demonstrate replication of the results due to the uniqueness of the study. However, a view proposed by Stake (1994:247) and Denscombe (2008:283) suggests that even though each situation may be unique, it is not obligatory to reject replication.

Lincoln and Guba (2005:129) and Denscombe (2008:283) suggest that the researcher should ensure that adequate background information and evidence is obtained and provided to enable the reader to make such transfers. The work of Marchionini and Teague (1987:20) and Krawczyk *et al.*, (2019:29) emphasise the significance of the researcher to include and highlight to the reader the boundaries of the research. Due to the critical aspect of transferability, the researcher included in the study participants from different parts of the world. Workshops were so designed to be held in various global locations (Krawczyk, *et al.*, 2019:29).

#### 4.4.4 *Dependability*

Lincoln and Guba (2005:129) argue that there is a close relationship between credibility and dependability, and that demonstrating the credibility of a study assists immensely in ensuring dependability. The researcher has achieved this by applying a mixed method triangulation design utilising qualitative, quantitative, and secondary data set.

#### 4.4.5 *Confirmability*

The work of Patton (2015:125) describes objectivity in science as concerned with the utilisation of measurements and instruments that are not reliant on human competence and judgement. However, Patton (2015:125) does concede the difficulty of safeguarding objectivity since questionnaires and measurement techniques in a qualitative study are designed by people (Patton, 2015:125).

As mentioned previously, the researcher applied the mixed method triangulation design in promoting confirmability and in order to reduce the effect of researcher bias. The researcher acknowledges his own prejudices and predispositions; however, the researcher believes that this was largely mitigated by utilising this research design and thereby increasing the integrity of the research results.

#### **4.5 Delimitation of the study**

The delimitations that characterise the limitation of the scope of the study include the boundaries of the study, such as sample size, the geographical location and setting of the focus groups, and the population traits. Currently, there are more than 450 electricity companies globally (Power Technology, 2019:17), and of these, only a small portion of these companies carry out research and development. The researcher is aware that it was a near impossibility to include all companies; both from a financial and logistical perspective.

These limitations posed practical challenges to the study in terms of a lack of financial resources and time constraints in carrying out a more detailed and thorough survey. Owing to this, the researcher narrowed down the scope of the study to a specific target population; namely, a global research association, of which its members (senior technology executives) comprise 63 global utilities who are involved in research and development. Of these 63 organisations, six were in the top 10 global companies by revenue, and the remainder were in the top 100 (Power Technology, 2019:17) and 15 countries were represented in the study.

#### **4.6 Ethics**

According to Dowse van Rensburg (2011:159), the following principles need to be applied in that respondents must give prior consent in terms of confidentiality, privacy, sensitivity, and anonymity before the research study can commence. Based on these principles, the researcher provided detailed material and information on the purpose of the study and the role of the participants.

A letter was prepared by the researcher and was sent to the IRO Secretary General for acceptance and signature. The letter also assured the IRO of member confidentiality and that anonymity would be protected (see Annexure 1).

## **4.7 Conclusion**

Chapter 4 has outlined the study design and methodology. Based on the research question, the study utilised a mixed method design, where the researcher's paradigm was aligned with his ontology of that of an objectivist. How knowledge is gained will be through the application of a systems' thinking approach and pragmatism, which supports the research process of a parallel triangulation design.

The aim of this mixed method design was to develop a conceptual framework for technology roadmapping that is responsive to the where the rate of technological adaptations and change outpace business processes. Thus, the research philosophy enabled the researcher to combine both inductive and deductive reasoning in this exploratory study.

The research aims and objectives and the practical considerations of the study were demonstrated and shown to be more appropriate to a parallel approach of qualitative focus group workshops, a quantitative survey with members, and a secondary data collection. For this reason, a mixed method triangulated design of qualitative semi-structured workshops and surveys, quantitative survey questionnaires, and secondary data was adopted and employed to generate both narrative and numeric data about the variables considered in this study.

## CHAPTER 5

### BRUSSELS, BERLIN AND SURVEY DATA ANALYSIS

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#### 5.1 Introduction

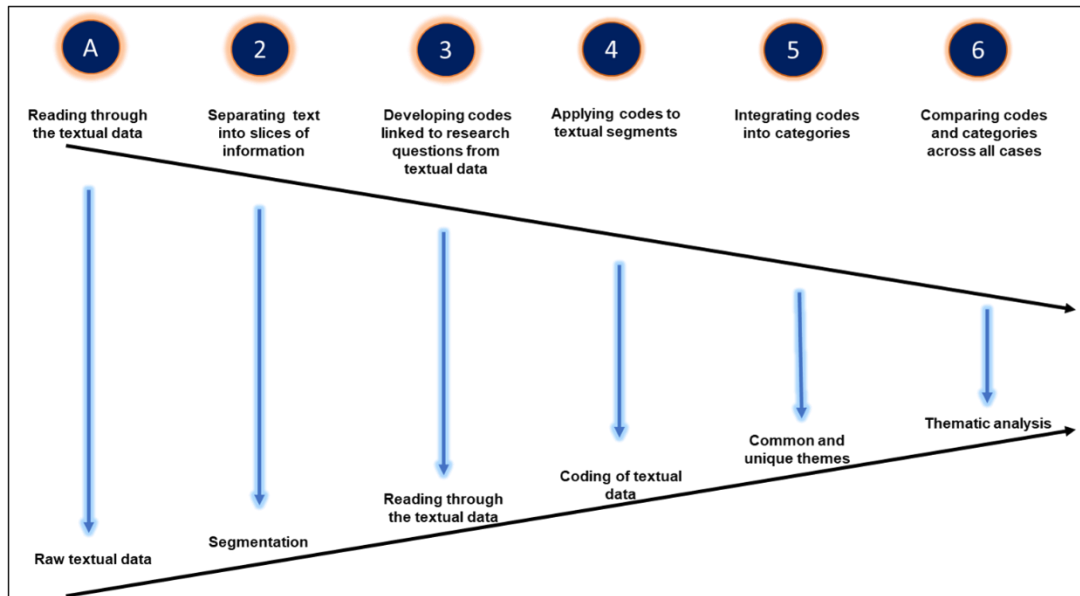
Chapter 4 introduced the methodology and research design to explore this thesis's research questions. The research methodology incorporated a mixed method approach that included both primary data (qualitative and quantitative) and secondary data where appropriate. This study's qualitative data collection phase applied a focus group approach which planned for three focus group workshops, approximately eighteen months apart. It is important to note that data generated during this phase could be subjected to group dynamics.

According to Levine and Moreland (1994:28), group interactions may stimulate individual group members' thinking, thus allowing individual group members to build on each other's ideas in exchanging ideas and information (Levine and Moreland, 1994:28). Furthermore, in individual interviews, the goal is to obtain personal opinions and feelings. In contrast, focus groups elicit various views, beliefs, and emotions within the group context (Gibbs, 2012:31), thus enabling the researcher to gain a more significant amount of information in a shorter period.

However, the third workshop was cancelled due to the onset of the COVID-19 pandemic and the impact of global regulations on travel. As a result, the researcher revised his approach to the data collection method and developed an adjusted survey questionnaire which considered the potential impact of COVID-19 in the planning process of technology roadmapping.

The data were obtained through focus group discussions and facilitation, primarily centred on collecting textual data. Two focus group sessions were held approximately 18 months apart. In addition, one qualitative survey was undertaken due to the third workshop being cancelled. The outputs of each focus group workshop session were

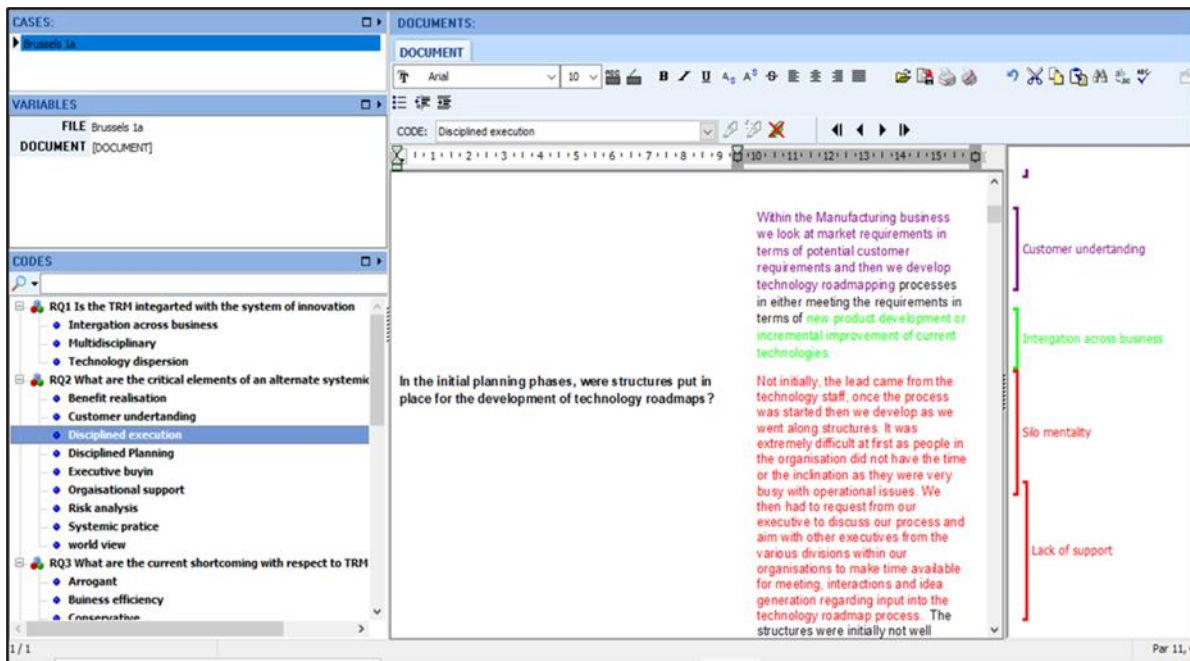
transcribed to construct textual data. The textual data for both the workshops and the survey were then loaded into a commercial software programme, and the textual coding and analysis were performed using QDA Lite. Figure 5.1 represents the thematic framework for the qualitative analysis.



**Figure 5.1: Thematic analysis for analysing qualitative data for this study**

*Source: Adapted from Ivankova and Stick (2007:11)*

An example of the textual coding and analysis performed in QDA Lite is shown in Figure 5.2. The coding and categories are associated with the study's research questions, open-ended questions, and textual responses.



**Figure 5.2: Example of textual coding and analysis on QDA Lite**

An important aspect to note was that before the two focus group (Brussels and Berlin) sessions commenced, an introductory quantitative survey was undertaken where both focus groups were asked the same questions.

## **5.2 Background to the Brussels and Berlin focus group workshops**

This section summarises the participant's attendance, affiliations and countries represented at the Brussels and Berlin focus group workshops. Most participants had extensive experience working in the power utility industry, ranging from 15 to 30 years and were mainly at the senior and executive levels.

The first focus group workshop was held in Brussels, and Table 5.1 outlines the number of IRO members attending the workshop. The table shows that there were 16 participants from 10 different countries globally.

**Table 5.1: Member participants attending the Brussels focus group workshop**

Sectors of Member participation	Number of Attendance	% of Total Participants	Country Composition
Electricity Research Institutes	7	43.7	China, Japan and Mexico and Belgium
Electricity Power Utilities	5	31.3	Japan, France, South Africa and Canada
NGO's	2	12.5	Japan
Electricity Manufacturers	2	12.5	USA
All Sectors	16	100	

The table indicates the make-up of the participants' industries represented were 43.7% from Electricity R&D organisations, 31.3% from Electricity Power Utilities, 12.5% from electricity-related NGOs and 12.5% from electricity manufacturers. A comprehensive global representation included participants from Europe, the Americas, South Africa, Mexico, China and Japan.

Table 5.2 outlines the number of individuals participating in the Berlin focus group workshop. It is important to note that this workshop occurred 18 months after the Brussels workshop. The table shows that there were 25 participants from 13 different countries across the globe.

As can be seen from the table, the participant representation was from the electricity R&D organisations (32.0%), electricity power utilities (60.0%), electricity-related NGOs (4.0%), and 4.0% from universities. In addition, a representation from across the globe included participants from Europe, the Americas, South Africa, China, South Korea and Japan.

An important observation was that there was a significant increase in the number of electricity utility participants compared to the Brussels focus group workshop.

**Table 5.2: Member participants attending the Berlin focus group workshop**

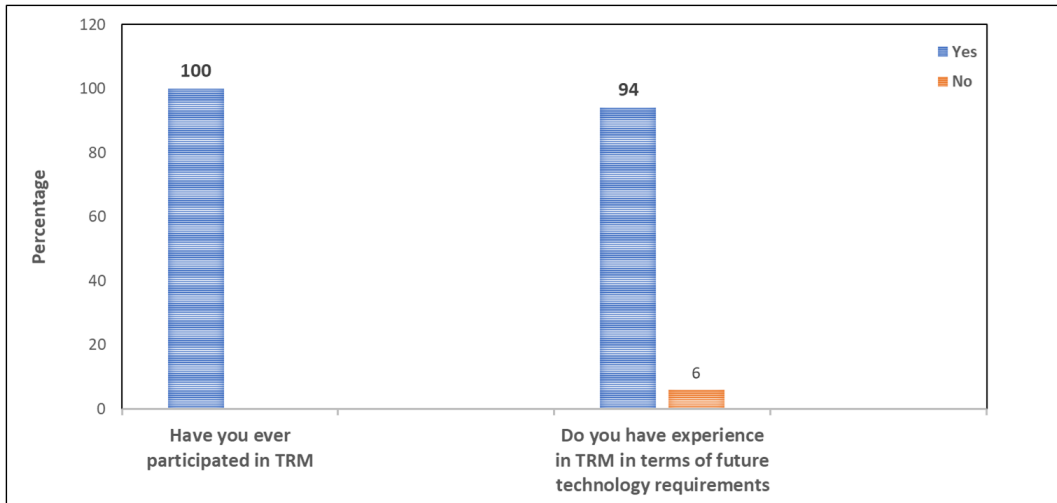
Sectors of Member participation	Number of Attendance	% of Total Participants	Country Composition
Electricity Research Institutes	8	32	China, Germany, Japan, USA, Mexico
Electricity Power Utility	15	60	China, Hong Kong, France, Italy, Canada, RSA, Turkey, Germany
Universities	1	4	Netherlands
NGO's	1	4	Japan
All Sectors	25	100	

## 5.3 Introductory quantitative survey

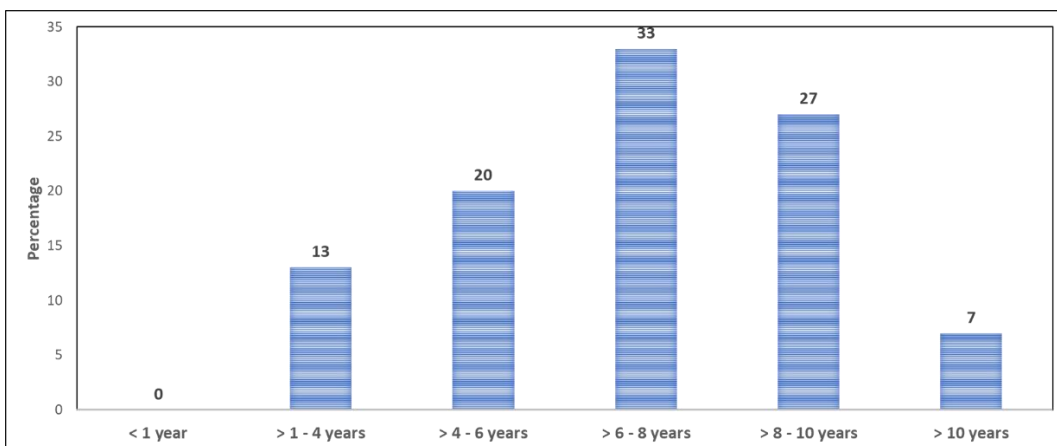
### 5.3.1 Brussels analysis

As mentioned in Section 5.1, a preliminary quantitative survey was undertaken with the Brussels focus group, and the results of the survey questions and responses are shown in Appendix 2 and 3. The results showed that all the participants had been active in the technology roadmapping process and activities and 94% in long-term technology planning (Figure 5.3). Only 6% had not been involved in long-term roadmapping planning activities.

Figure 5.4 indicates the number of years the participants have been active in TRM activities. The data confirm that most of the participants (87%) were engaged in TRM activities for four years or longer.

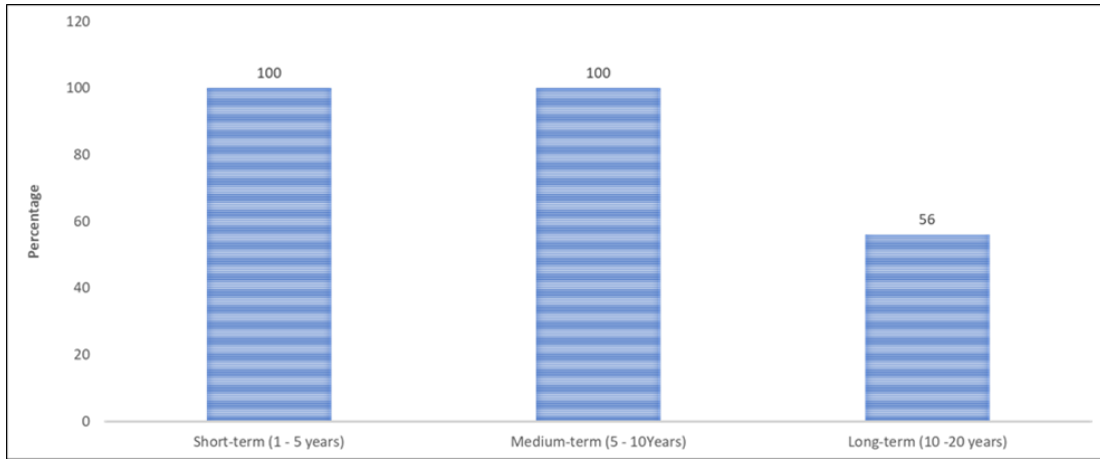


**Figure 5.3: Experience of Brussels focus group members involved in TRM activities**



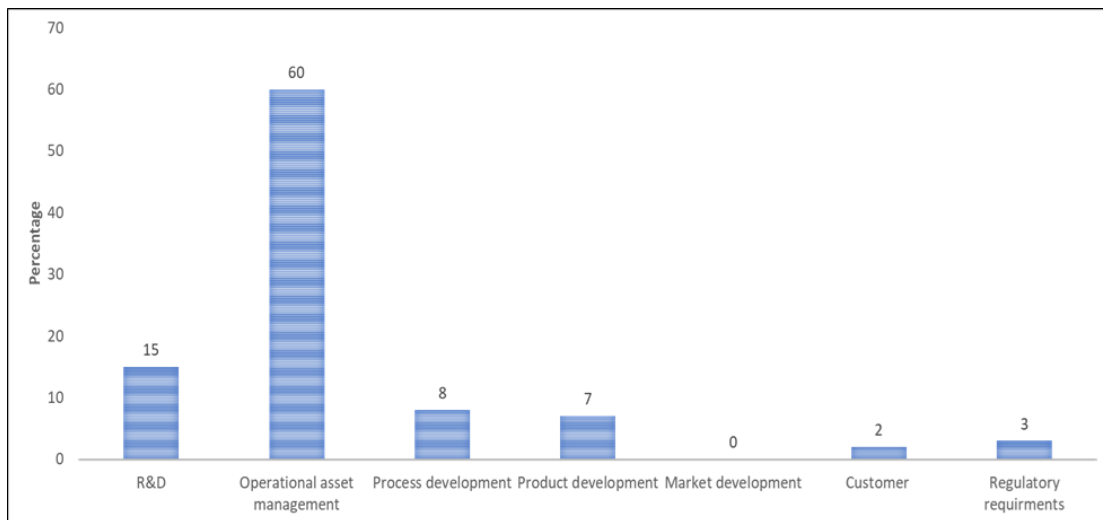
**Figure 5.4: Number of years Brussels focus group members involved in TRM activities**

The dynamics of the group’s interactions revealed similarities and differences in opinion in some cases. For example, the question related to the TRM planning horizon in years within the participant’s organisations was that the short to medium-term approach dominated the planning phase. Interestingly, the manufacturing and R&D industry participants felt that long-term planning was critical and imperative when considering future and disrupted technologies (See Figure 5.5).



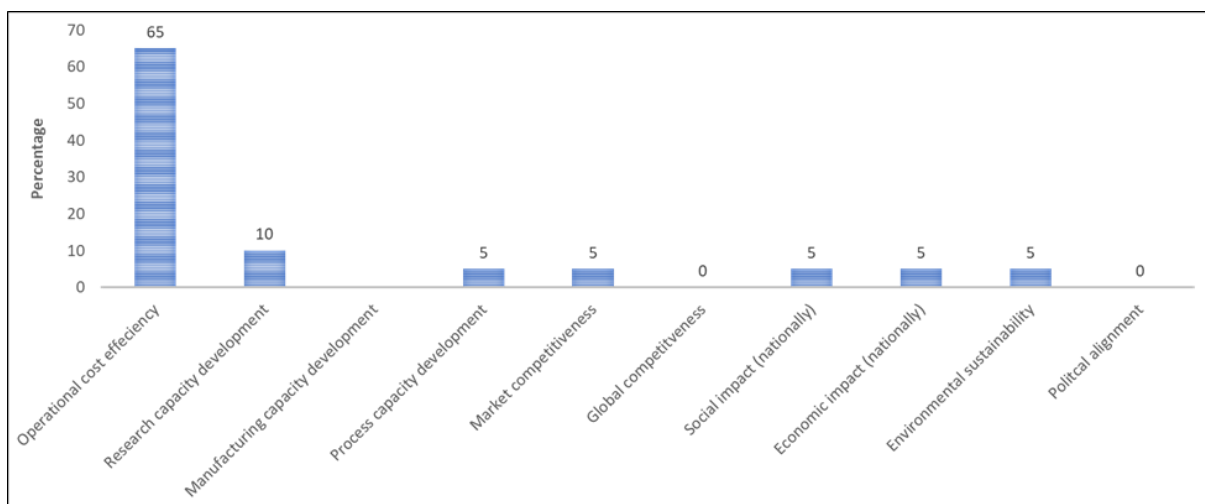
**Figure 5.5: What was the planning horizon in years of your organisation TRM?**

Figure 5.6 indicates that the TRM exercise's primary motivation was primarily focused on operational improvements and management (60%), followed by research and development on current and new technologies. Interestingly, customers were not the primary motivation for undertaking the TRM exercise. It appears that even though the regulatory requirements scores were low, in terms of the motivating force behind the TRM exercise, operational asset management and technology development (R&D) are closely linked to meeting regulatory requirements.



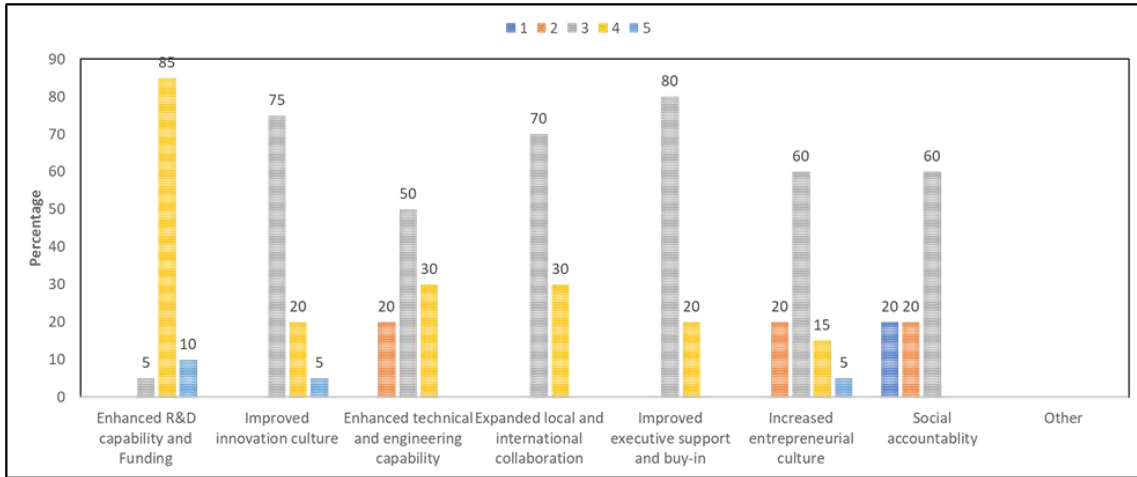
**Figure 5.6: What was the primary motivation for undertaking the TRM?**

Figure 5.7 validates the previous question that the TRM outcomes' primary focus was operational asset management; i.e. operational improvements and R&D. It also noted that the feedback related to social impact at the national level, environmental sustainability and political alignment was low. These results indicate a strong internal organisational focus; i.e. the operational focus, when undertaking the roadmapping process. In addition, limited attention was given to the meso- and macro environments, respectively, as depicted by the low frequency given to global competitiveness, social impact, economic impact, and environmental sustainability.



**Figure 5.7: Based on the above question, what are the likely impacts of the technological outcomes?**

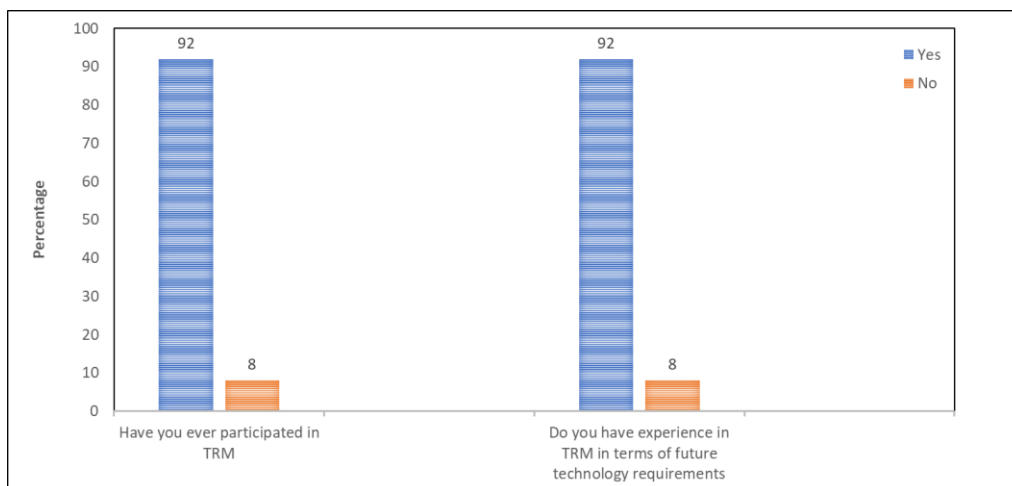
Figure 5.8 indicates the rank of what the group participants felt regarding the main factors that influenced the outcomes of the TRM process. The figure shows that enhanced R&D capability was the most important, followed by improved innovation culture, expanded local and international collaboration, improved executive support and buy-in and increased entrepreneurial culture, which was deemed the most critical influential aspects of the outcomes. This was expected, as the group's participants were primarily involved in their organisations' R&D, innovation, and technology roadmapping activities.



**Figure 5.8: What were the main factors that influenced the TRM outcomes (1=least important and 5=most important)**

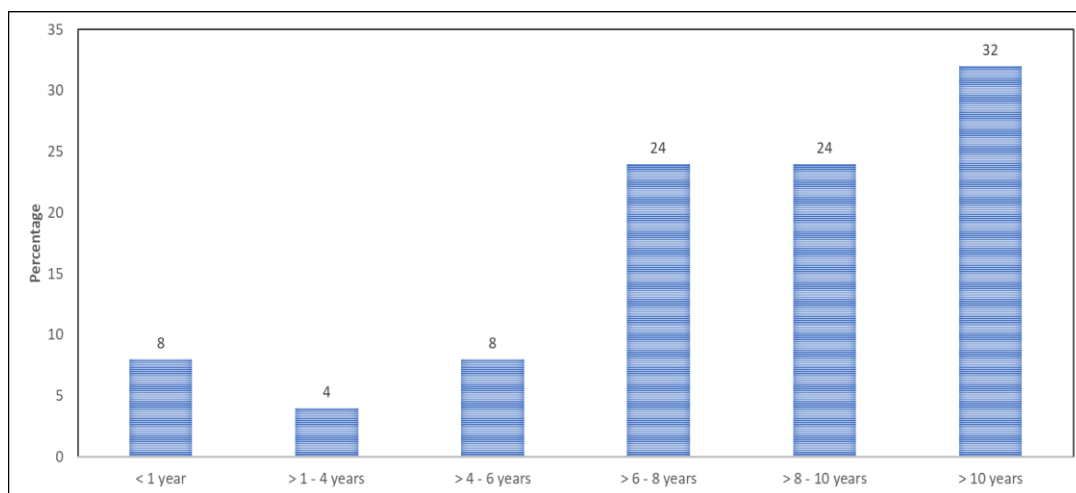
### 5.3.2 Berlin quantitative analysis

As mentioned in Section 5.1, a preliminary quantitative survey was undertaken with the Berlin focus group, and the results of the survey responses are shown in Appendix 4. In addition to analysing the Berlin data, this section will also undertake a comparative analysis between the Brussels and Berlin datasets. Figure 5.9 indicates that most participants have been engaged in technology roadmapping activities and long-term technology planning. These results are comparable with the Brussels results.

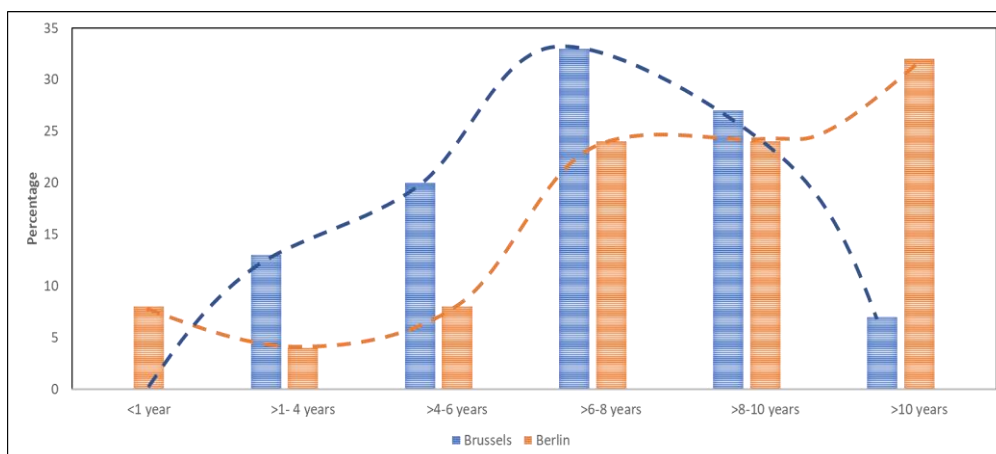


**Figure 5.9: Experience of members involved in TRM activities**

Figure 5.10 indicates the number of years the participants have been active in TRM activities. The data confirm that 96% of the participants were engaged in TRM activities for four years or longer, and 56% were engaged in TRM for eight years and longer. This is in sharp contrast to the Brussels results, where only 7% had in 10 years or longer involvement in TRM activities compared to the Berlin group of 32% (Figure 5.11). The researcher suggests that these differences could be due to the Berlin group being more experienced in roadmapping processes and techniques than the Brussels participants.

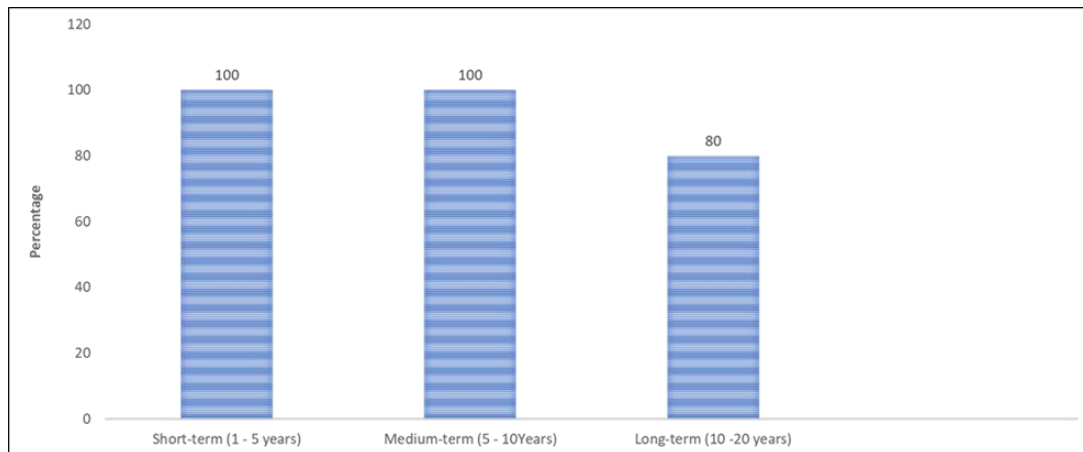


**Figure 5.10: Number of years members involved in TRM activities**



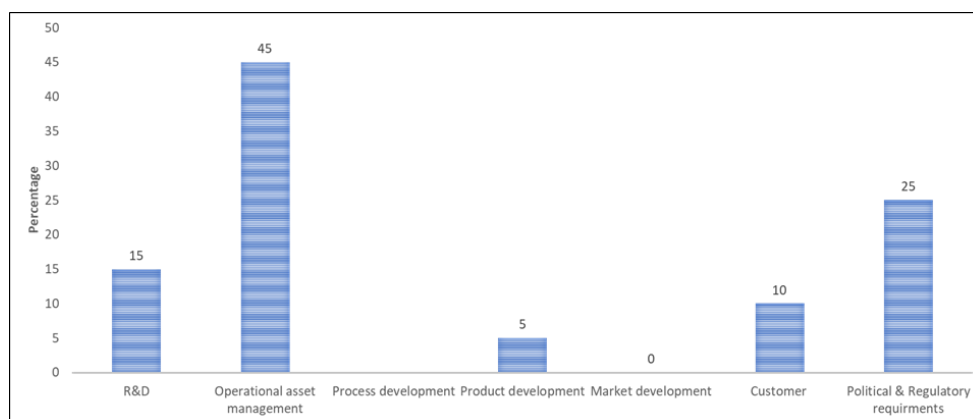
**Figure 5.11: Number of years the Brussels and Berlin members involved in TRM activities**

The question related to the TRM planning horizon in years within the participant's organisations indicated an increase (25%) in the attention given to long-term planning (Figure 5.12). This was in contrast to the Brussels results, where the primary focus was short and medium-term planning.



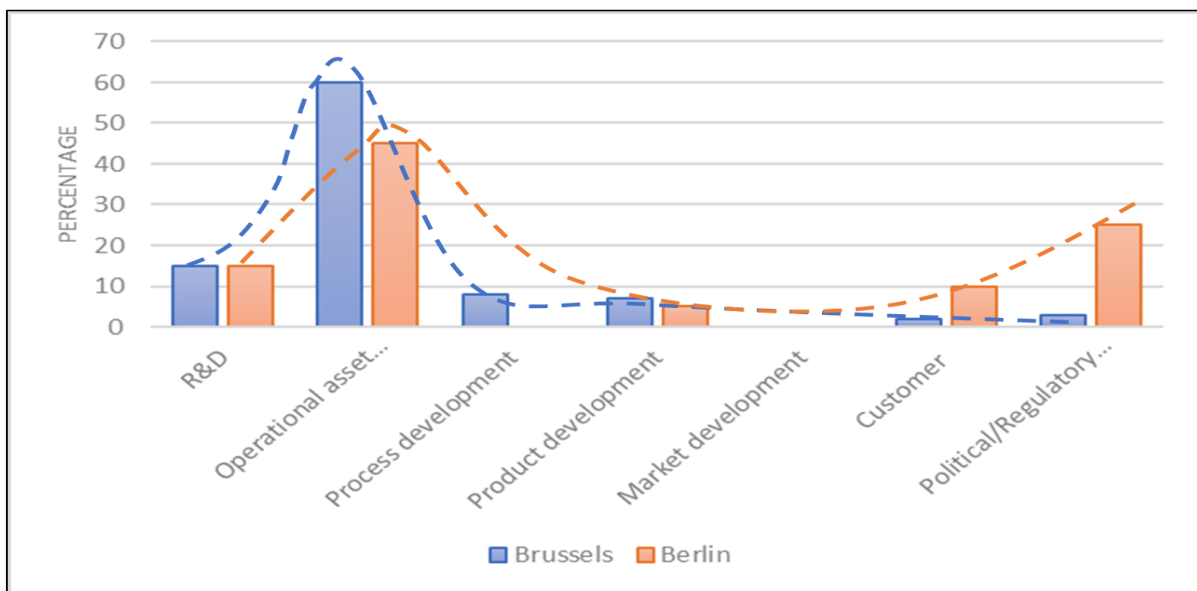
**Figure 5.12: What was the planning horizon in years for your organisation's TRM?**

Figure 5.13 indicates that the TRM exercise's primary motivation was primarily focused on operational improvements and management issues (45%), followed by political requirements (25%), research and development (15%), and customers (10%).



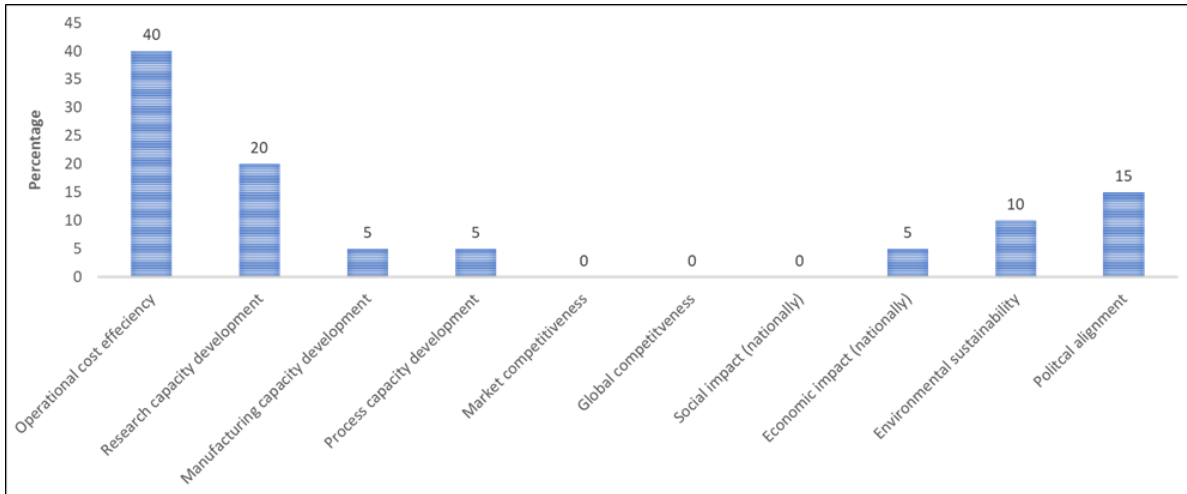
**Figure 5.13: What was the primary motivation for undertaking the TRM exercise?**

This sharply contrasts the results obtained from the Brussels survey, where the TRM exercise's dominant motivation was operational asset management followed by R&D development (Figure 5.14). The Berlin results displayed a somewhat diverging view in that operational focus decreased, and customers and political and regulatory importance grew significantly. Thus, the Berlin results indicated a shift in thinking to customer understanding and necessitated including the political and regulatory environment as a primary motivation in the TRM exercise.



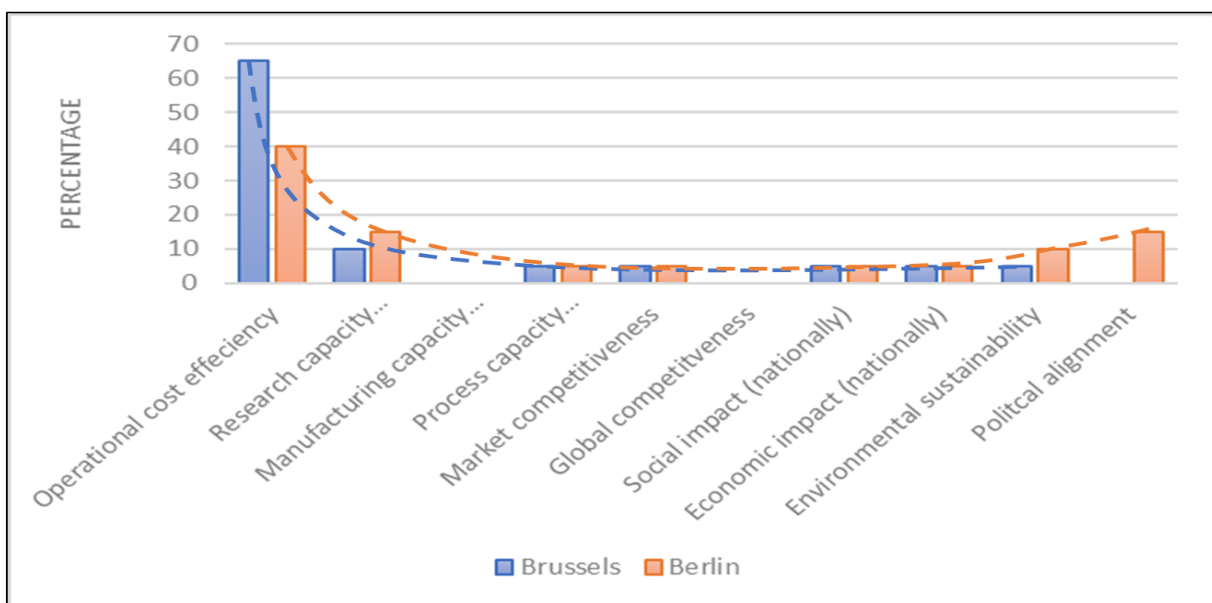
**Figure 5.14: What was the primary motivation for undertaking the TRM exercise?**

Figure 5.15 validates the previous question asked in that the primary focus of the TRM outcomes was seen as operational cost efficiency (40%), R&D (20%), political alignments (15%) and environmental sustainability (10%). Also noted was that environmental sustainability and political alignment were considered essential factors in the TRM exercise. Results showed that more importance was allocated to the external environment, indicated by the fact that political alignment, environmental sustainability and economic impact made up 30% of the total bearing of the technological outcomes.



**Figure 5.15: Based on the above questions what is the likely impact of these technological outcomes?**

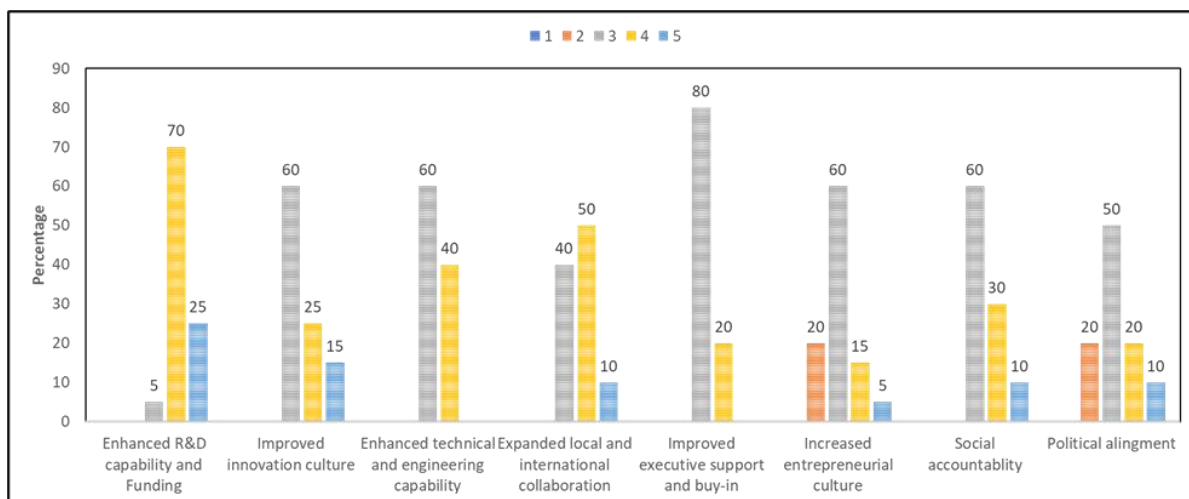
Figure 5.16 shows that the Brussels results placed significant importance on operational efficiency (65%), low importance on environmental sustainability (5%) and no regard for political alignment. In contrast, Berlin's results indicated a decrease in operational efficiency (40%) and an increase in environmental sustainability (10%) and political alignment (15%). What is apparent from the figure is that an emerging trend occurred over the eighteen-month period, where the focus of the Brussels results indicated a predominantly inside operational perspective. In contrast, the Berlin results leaned toward a more outward-thinking ecosystem perspective.



**Figure 5.16: Based on the above questions what is the likely impact of these technological outcomes?**

Figure 5.17 indicates the group response in terms of the main factors that influenced the outcomes of the TRM process. The figure indicates an enhanced R&D capability as the most important, followed by improved innovation culture, expanded local and international collaboration and improved executive support. In addition, what was noticeable was an increased focus on social accountability compared to the Brussels results.

Finally, a critical fact noted when comparing the two datasets is that Brussels did not consider political alignment an essential factor. In contrast, Berlin's responses placed significant importance and consideration on political alignment regarding the likely impacts of technological outcomes in the TRM process.



**Figure 5.17: What were the main positive factors that influenced the TRM outcomes?**

*1=least important and 5=most important*

In the comparative analysis of the Brussels and Berlin results, it was noted that a notable changing trend occurred over the 18 months. Results indicated a gradual shift in thinking from the Brussels respondents from predominantly an internal business focus perspective to a more outward-looking perspective and ecosystem understanding from the Berlin participants. It is suggested from the results that the

Berlin respondents exhibited a more holistic understanding of ecosystem drivers (environmental and political alignment) and the potential consequential impacts on the roadmapping planning approach and, thus, the technological outcomes.

## **5.4 Focus group workshop**

This section presents the results of the qualitative focus group workshop held in Brussels. As mentioned in Chapter 4, the open-ended questions assisted and stimulated group thinking, discussions, group interactions, and individual and group exchanges of ideas, allowing group members to build on each other's' ideas and concepts.

The same open-ended questions were posed at both the Brussels and Berlin workshops to ensure the continuity of the study (see Appendix 5). During the facilitation process, the researcher made a conscious effort that no one focus group member dominated the discussions, thereby impacting the group dynamics through peer pressure or biased information processing. The facilitation applied by the researcher was an invitation and non-threatening approach to open-ended questions, which allowed all members of the focus group to participate (Nowell *et al.*, 2017:13). Figure 4.4 in Chapter 4 illustrates the researcher's facilitation approach.

At the commencement of the workshop, the researcher discussed the workshop's aim and purpose to ensure that all participants were clear regarding the requirements and intent of the process. In addition, the researcher introduced the current concepts and definitions of technology roadmapping and technology roadmaps to the focus group.

Technology roadmapping is a planning process seen through a strategic lens by organisations. Technology alternatives and approaches are considered to address, understand, and develop new and current technology pathways for organisational value and competitiveness (Albright and Kappel, 2003:40; Phaal *et al.*, 2013:17, 2016:12; Letaba, 2018:75; Kerr and Phaal, 2022:15).

A technology roadmap is a visual presentation communicating a plan for an organisation's technology initiatives. It typically outlines when, why, and what technology solutions could be implemented to help organisations move forward to stay relevant and competitive (Albright and Kappel, 2003:40; Phaal *et al.*, 2013:17, 2016:12; Farrukh *et al.*, 2014:62; Ilevbare *et al.*, 2011:17; Kerr and Phaal, 2022:15).

Understanding organisations' developmental approach and process of technology roadmapping is critical to distinguish and categorise how, when, and why organisations consider the implementation method. The researcher selected three principle activities:

1. Technology roadmap development process.
2. The strategic role of TRMs.
3. The critical success factors for TRMs.

The activities were discussed with the focus group to set the context. The activities had several open-ended questions presented to the focus group for discussion and response. In each activity, open-ended questions were presented for discussion.

Several themes were identified in examining and analysing the qualitative data (i.e. focus group interviews and the researcher's notes and observations). These were then grouped with the respective selected activities. Four themes were developed, each with an associated category and code for both the Brussels and Berlin focus group responses.

The themes were pre-determined and were aligned with the research questions (RQ) and objectives of this thesis: a) Organisational innovative capacity aligned to RQ1, with the associated category absorptive capacity, b) Business leadership practice aligned to RQ2, with the associated category critical elements of a TRM framework, c) Organisational behaviour aligned with RQ3 with the associated category organisational process obstacles, and d) Systems thinking prerequisites aligned to RQ4, with the category critical constructs.

### 5.4.1 Brussels focus group workshop

As described in section 5.2. of this chapter, 16 IRO members participated in this focus group workshop. The participants represented were from Electricity R&D organisations (43.7%), Electricity Power Utilities (31.3%), electricity-related NGOs (12.5%), and 12.5% from electricity manufacturers. A relatively broad representation from across the globe was present.

Codes were developed in the thematic analysis and were linked to the categories are shown in Table 5.3. As described in section 5.2.2, the themes and categories were aligned with this study's research questions and aim. Appendix 6 shows the focus group responses, and Appendix 7 the coded frequencies that constituted each category.

**Table 5.3: Brussels focus group themes, categories, and codes**

Themes	Categories	Codes
Organisational innovative capacity	Absorptive capacity	<ul style="list-style-type: none"> <li>• Multidisciplinary</li> <li>• Knowledge sharing</li> <li>• Technology dispersion</li> </ul>
Business leadership practice	Critical elements of a TRM framework	<ul style="list-style-type: none"> <li>• Benefit realisation</li> <li>• Customer understanding</li> <li>• Disciplined execution</li> <li>• Disciplined Planning</li> <li>• Executive buyin</li> <li>• Organisational support</li> <li>• Risk analysis</li> <li>• Systemic practice</li> <li>• World view</li> </ul>
Organisational behaviour	Organisational process obstacles	<ul style="list-style-type: none"> <li>• Arrogance</li> <li>• Operational perspective</li> <li>• Conservative</li> <li>• Customer ignorance</li> <li>• Lack of disciplined execution</li> <li>• Linear thinking</li> <li>• Corporate politics - Lack of support</li> <li>• Least cost technology</li> <li>• Lack of Monitoring, reporting and evaluations</li> <li>• Organisational ignorance</li> <li>• Political interference</li> <li>• ROI lacking</li> <li>• Shareholder first</li> <li>• Short-term strategic focus</li> <li>• Silo mentality</li> <li>• Sponsor influence</li> </ul>
Systems thinking prerequisites	Critical constructs	<ul style="list-style-type: none"> <li>• Agility</li> <li>• Climate change</li> <li>• Environmental impact</li> <li>• Strategic vision</li> <li>• Organisational resilience</li> <li>• Political environment</li> <li>• Systems thinking</li> </ul>

#### 5.4.1.1 Category: Absorptive capacity

This category addressed the focus group's perception of an organisation's ability to recognise the value of new technological evidence, assimilate it, and apply it for commercial and social gain. Figure 5.18 shows the coded analysis of the frequency of words per code with specific reference for the category 'absorptive capacity'.

The questions posed to the focus group were related to some of the key strategic factors that influenced their approach to technology roadmapping outcomes. The figure shows the coded frequency of the category's word count with absorptive capacity in green. According to the focus group's perceptions and responses, short-term goals and targets clouded the organisation's ability to recognise technology value. However, in some instances, knowledge sharing does happen within and external to the organisation through Joint Ventures (JVs) and partnerships. A question posed to the focus group was;

*What were the main strategic factors that influenced your organisation's approach to technology roadmapping outcomes?*

In response to this question, a much-mentioned comment from the focus group was:

Code 2) Multidisciplinary: *Knowledge sharing is the driver for looking at developing strategic partnerships so that we can share risk and costs.*

Moving on from the above response, the value of mutual benefits was also highlighted. This response aligns and converges with quantitative analysis undertaken with this group, in that they considered that the main factors of the TRM outcomes were the development of an improved potential for local and international collaboration leading, an improved innovation engineering capability leading to an enhanced R&D capability and funding. However, a critical opinion expressed by all the focus group participants related to knowledge sharing was that:

Code 2) Multidisciplinary: *Partnerships and JVs are difficult to manage.*

The above response is primary because partnerships demand a more rigorous management approach. It was further mentioned that, within the coalition, individual partners always considered maximising their benefits first as a primary goal rather than considering the overall partnership benefits.

A further response from the focus group related to technological issues under the knowledge-sharing code was:

*Code 3) Technology dispersion: Large-scale and centralized renewable power generation (such as wind power generation, solar generation) and its integration within the business is important ... in improving generation coordination within the business to cope with intermittence.*

It was observed that participants from the manufacturing segments of the focus group were much more inclined (as opposed to the power utility sector) to share technology in a multi-disciplinary way, both internally and externally. On the other hand, the Asian participants were more aligned with the concept of an interdisciplinary approach to technology issues and development which aligns with the quantitative survey undertaken with the group.

A critical response from the focus group related to the category absorptive capacity and the associated code knowledge sharing was when this question was posed;

*How long did your organisation's development roadmapping process take from start to completion of the final product?*

*Code 1) Knowledge sharing: It generally took around 12-18 months to come up with the final report. It then took a further six months to share with the organisation ... In some instances, it took much longer due to the fact that we had poor processes and that it became a 'political ball' within our organisation.*

The researcher found this to be a significant response as it has a critical bearing on an organisation's absorptive capacity (RQ1) and how an organisation could recognise

technology value and benefits, and then the ability to integrate this into its technology strategy for both commercial gains and social benefits which is linked to (RQ3). The groups' concluding response from the focus group further confirms the point made in the previous sentence, which was:

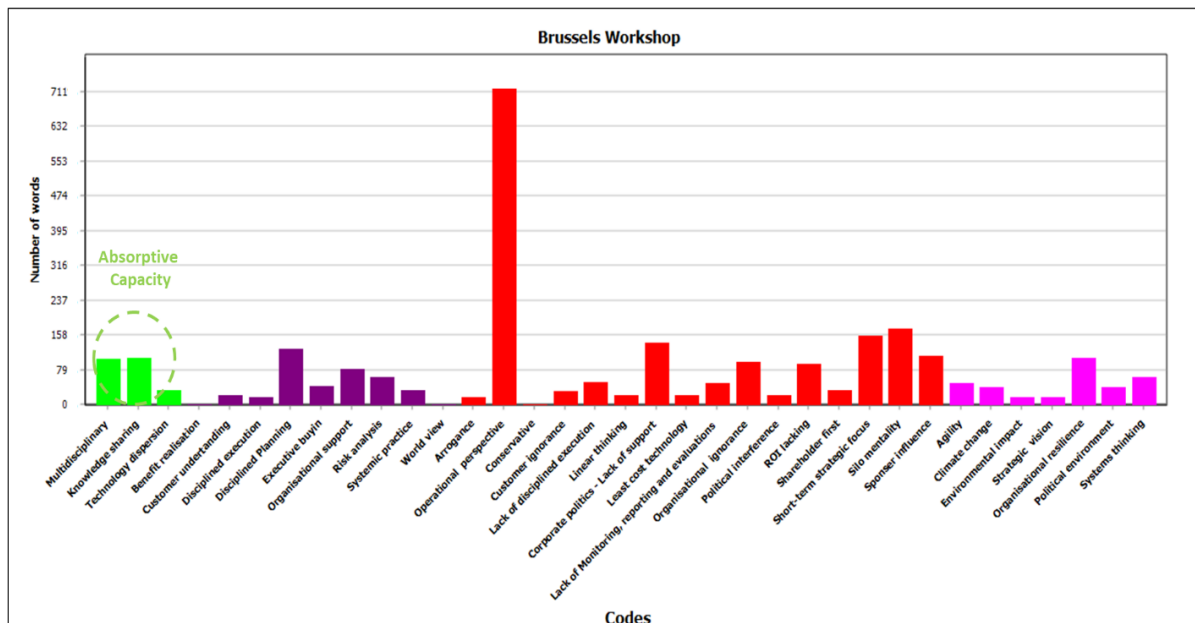
Code 1) Knowledge sharing: *This resulted in many instances that the final report was never completed and presented.*

By interacting with the focus group on the category 'absorptive capacity', the researcher could observe how the participants responded. In addition, the researcher was able to detect the various group dynamics within the focus group. Finally, from the coding analysis results in this category, the 'knowledge sharing' and 'multi-disciplinary' codes were concerning for the focus group in the TRM process.

Further, the code frequency results related to 'technology dispersion' indicated minimal importance, indicating that the group's perception was that it was not significant. It became apparent from the focus group discussions that 'absorptive capacity' from a knowledge-sharing perspective was seen as critical.

However, during the debate, what emerged was the sense among the majority of focus group participants that the organisations they represented did not value the TRM process and outputs, thus resulting in the lack of knowledge sharing and technology dispersion. This aligns with the quantitative survey from this group, where the majority (80%) were neutral on the question of executive support and buy-in.

However, 20% believed that it was an important consideration in terms of an organisation's ability to identify, assimilate and share knowledge. It is suggested that these results reflected a shift in thinking by the focus group from the initial neutral stance (in the quantitative survey) to a concern that executive support and buy-in are imperative for the organisation's technological growth and development. See below for a graphical representation of the frequency of 'absorptive capacity'.



**Figure 5.18: Frequency of coded words for the category 'absorptive capacity'**

#### 5.4.1.2 Category: Critical elements of a TRM framework

This category addressed the focus group's perception of the significant business leadership practices and elements required for developing an organisational TRM. A questions posed to the focus group was associated with some of the key strategic factors that influenced the group's approach to business leadership approaches and organisational culture concerning TRM processes and outcomes.

Figure 5.19 shows the coded frequency for the word count of the category 'critical elements of a TRM framework'. The codes are shown in purple. According to the focus group's responses, the organisational leadership's ability to recognise the value of the technology roadmap process and strategic outputs was lacking in several areas. For example, when asked the question about the TRM planning process and who initiated the process, the following was given:

Code 5) Executive buy-in: *It is seldom initiated by the CEO and executive in most cases; however, in some instances, the appropriate R&D executive may well request the development of a TRM process.*

Code 2) Customer understanding: *Within the manufacturing business we look at market requirements in terms of potential customer requirements and then we develop technology roadmapping processes.*

Code 6) Organisational support: *This resulted in the technology roadmap not fully being accepted by various parts of the business. We believe if there was strong CEO and executive support, the process would have been a lot more accepted and would have had much more strategic value to the business and the line divisions.*

It became clear from the focus group discussion that organisational support and knowledge sharing are vital ingredients for the TRM process's success, and the quantitative survey's results support this. In addition, customer understanding was mentioned in the discussions; however, not at the same frequency as the other codes in this category which are aligned with the quantitative results. This suggests that the focus group did not consider understanding as an essential driver in the planning phase of the TRM. A further question posed under this category was:

*In the initial planning phases, were structures put in place for the development of technology roadmaps?*

The following responses were given:

Code 4) Disciplined planning: *The structures were initially not well developed, and as such, the process was hampered.*

Code 4) Disciplined planning: *Our organisation which is an R&D only business, structures were well developed in terms of the process.*

Code 6) Organisational support: *There was a high-level commitment which made the process that much easier to manage in terms of our time frames and final outputs.*

The discussions around the question led to stimulating and at times, vigorous debates among the focus group participants. It became clear to the researcher that there were two opposing responses. The first was from the participants from the utility businesses. They felt that their organisations' planning, structures, and processes were not appropriately applied. This can be seen from their responses in terms of the code of disciplined planning and placed high importance on this aspect.

From the responses, it can be observed that disciplined planning and organisational support were considered critical success drivers in terms of the TRM planning process. However, the participants from the R&D institutes felt that planning, processes, and structures were well managed. This response is confirmed by the quantitative survey results where industrial and R&D institutes held the view that appropriate planning, particularly long-term planning, was important when considering future disruptive technologies. These responses are key contributors to RQ1, RQ2 and RQ3, of this study

A question asked of the focus group was:

*When considering the operational issues in your TRM process, what are the key issues and challenges that you need to build into your roadmap with respect to renewables and why?*

The group responded in the following way:

*Code 7) Risk Analysis: Renewables is something that we need to consider in the long-term. We will be forced sometime in the future through government policy to consider...it is important to note that integrating renewables into our current system is extremely problematic and, as such, will incur additional costs and major problems in our business if we are forced to apply. Power plants are extremely costly and considering the life of plant. Current fossil and nuclear plants must take preference over new technologies purely from a cost perspective.*

In response to this question, there was an understanding that renewable energy is something to consider only in the long-term. This view is aligned with the quantitative results, confirming the low importance of environmental sustainability and social accountability. Nevertheless, it was clear from the group's view that there were critical risks associated with a forced transition from fossil fuels to renewable forms of energy in terms of the unintended costs related to sunken costs. Therefore, risk analysis was considered an essential driver in the TRM process.

According to the focus group's perceptions related to the development of TRM cooperatively with external stakeholders, there was agreement that this was an essential factor. However, due to the competitive and confidential nature of the process, it was not considered appropriate, which was also confirmed in the quantitative survey results, where customers were given a low rating. In addition, a further question was posed concerning sharing:

*Was the TRM process integrated into other internal strategies, and if so, how were they interrelated?*

The focus group responded as follows:

Code 2) Customer understanding: *In the R&D institutes, customers were involved in the process, mainly at the end of the process and feedback on the final TRM report.*

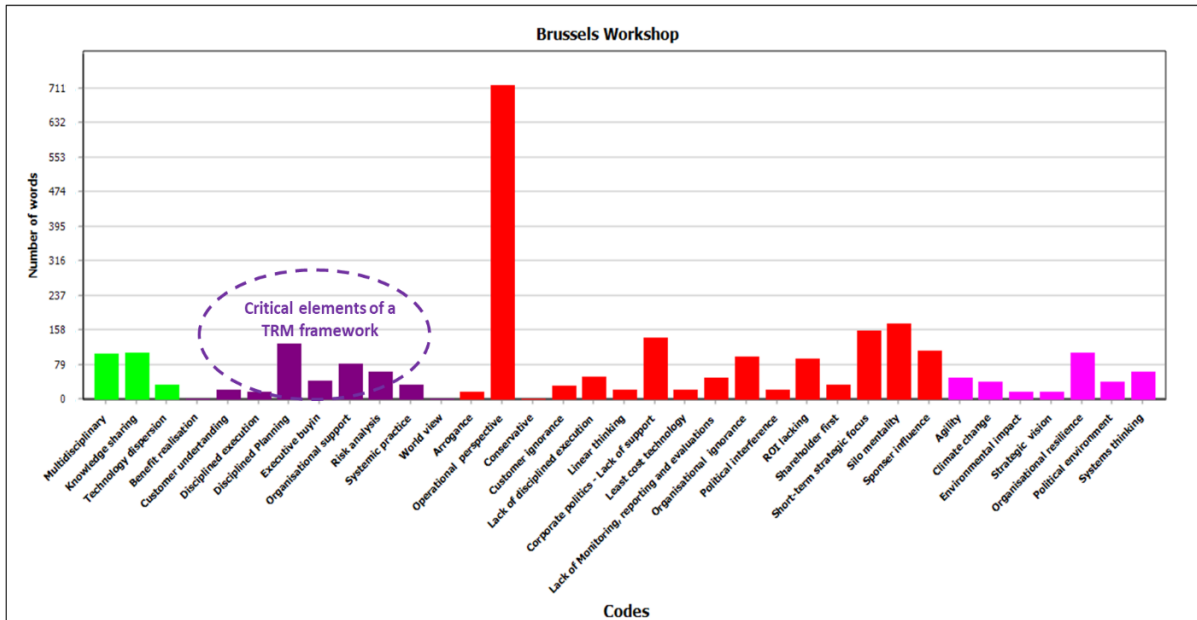
Code 2) Customer understanding and Code 8) Systemic practice: *In Japan, we also tend to consider the 'Society 4' model; however, we only consider and we need to make much more effort in building the model into our planning process.*

Code 5) Executive buy-in and Code 4) Disciplined planning: *In electricity utilities, in most cases, they were not integrated into other organisational strategies...in most cases, the rest of the organisation did not care about the output of the technology roadmap. It was seldom integrated fully into the organisation's business plan.*

There was a clear distinction between the participants from the R&D organisations' approach to customer involvement and electricity utilities. R&D organisations tended to involve customers in the TRM process only at the end stages. In contrast, the electric utilities did not consider including customers at all. A critical comment made by several participants was that the TRM outputs were not always considered in their organisation's strategies. It became clear from the discussions that executive support influenced the success or failure of the TRM process within organisations by way of the following response:

*Code 5) Executive buy-in: Yes, executive support is crucial for the success and role of the TRM. Without executive support funding, rollout and implementation would not happen in the organisation. In some cases, executives tend only to use the TRM for their own gain. Once the final report is done and presented, executives tend to move on to their next big project. So lack of commitment does happen in instances that negatively impact the TRM team and process.*

The researcher observed how the participants reacted and responded when interacting with the focus group on the category 'critical elements of a TRM framework'. The group dynamics within the focus group were highly passionate in that, in order to ensure that the TRM created value and benefits for the organisation, four critical codes were highlighted; disciplined planning, organisational support, risk analysis and systems practice, which must be seen as substantial inputs to both RQ2 and RQ3. See below for a graphical representation of the frequency of 'critical elements of a TRM framework'.



**Figure 5.19: Frequency of coded words for the category 'critical elements of a TRM framework'**

#### 5.4.1.3 Category: Organisational process obstacles

This category addressed the focus group's perceptions of the impediments and shortcomings experienced in their organisations during the TRM process. Questions posed to the focus group were about the key obstacles and shortcomings experienced during the development of the TRM processes. Figure 5.20 shows the coded frequency (in red) for the word count of the category 'organisational process obstacles'. As the focus group started to debate the issues around organisational process obstacles, it became evident that the participants raised similar points when questioned. The first question asked was:

*Who sponsors the development of TRM?*

As a result, the focus group had the following comments:

Code 15) Silo mentality: *It generally starts within the R&D division of the company which in some cases are centrally located with corporate or in other cases a decentralised function. It is seldom initiated by the CEO.*

Code 10) Organisational ignorance: *Very seldom, if not at all, does technology strategy/TRM get initiated at the executive level... It is in most cases a bottom-up approach, developed by technologists in support of and for organisational benefit.*

It became clear from the above discussion that there was sensitivity to the fact that they (the group) believed they were not seen as critical resources. This was seen by the fact that the organisation had no buy-in and that the roadmap was for the researcher's use only. The perception created was that the TRM played a minor role in developing the organisation's technology strategy. The codes further confirm this lack of support, organisational ignorance and, to a certain degree, sponsor influence, as seen in Figure 5.20. The quantitative survey indicated a relatively neutral stance regarding executive support and buy-in.

The following question was posed to the group related to the planning phase and structures deployed:

*In the initial planning phases, were structures put in place for the development of technology roadmaps?*

The focus group discussed as follows:

Code 15) Silo mentality: *Not initially, the lead came from the technology staff, once the process was started then we develop as we went along structures. It was extremely difficult at first as people in the organisation did not have the time or the inclination as they were very busy with operational issues.*

Code 1) Arrogance Code and 4) Customer ignorance: *The structures were initially not well developed and as such the process was hampered. Not all in the organisation was involved thus making the outcome not fully appreciated. This resulted in the technology roadmap not fully being accepted by various parts of the business.*

*Code 7) Corporate politics – lack of support: We then had to request from our executive to discuss our process and aim with other executives from the various divisions within our organisations to make time available for meeting, interactions, and idea generation regarding input into the technology roadmap process.*

It was evident from the above responses from the focus group that crucial shortcomings in the planning and developmental stages of the TRM were consistently focused on internal issues or even to the point of defining them as ‘wicked problems’ of silo mentality related to corporate politics and thus leading to a consistent lack of support from various divisions within their organisations. The participants further elaborated on this, and followed up with the following response related to the question posed:

*To what degree did the sponsor/s have a significant impact on the methodology applied during the TRM development?*

The following were key responses:

*Code 16) Sponsor influence: Initially the sponsors (in general) in instances when we had one, in many cases tried to influence the direction of the process and methodology. In many cases succeeding, and all it became was the sponsors/executives/CEO's view of what the outcome should be of the technology roadmap from a technological perspective. This is the case at times much to the dissatisfaction to the developers. Yes, so in most of the cases sponsors did have an impact on the eventual outcome of the TRM and thus on the approach and methodology.*

The above response further led to interesting discussions and responses related to the strategic approach of the TRM concerning sponsor influence. The conversation then led to the following question posed to the group:

*What were the main strategic factors that influenced the approach to technology roadmapping outcomes in your organisation?*

This was extremely well debated amongst the group, with the following aspects noted:

*Code 2) Operational perspective: Operational issues are key to the survival of our business. We focus on our current assets so in terms of quality of supply. So our key driver in our approach to roadmapping is operational performance and thus asset management.*

*Code 2) Operational perspective: Operational issues (asset management). i.e. business efficiency, was the most important driver as it was to ensure sustained and optimal business service and thus revenue to our shareholders, thereby driving shareholder value.*

*Code 2) Operational perspective: It is important to note that the energy business is a long-term conservative business as we run our plants for 40 years or more. Thus, when making technology decisions, we need to be conservative in our approach. You must note that the energy business is a multi-billion dollar business and as such we are extremely risk adverse.*

*Code 2) Operational perspective and Code 14) Short-term strategic focus: This mean that if we could improve on the operational aspect of our business, operational cost would decline thus improving our review stream. Keeping our technical side of our business well run, e.g. managing our assets would have a huge impact on our business from a financial perspective and operational perspective... Of course, regulatory considerations are critical in meeting the requirements of our regulator. It was our view that these requirements were integrated into our operational and asset management programme.*

The focus of the TRM process was undoubtedly aimed at short-term strategic drivers and operational perspectives of the business. The code operational perspective dominated this category in terms of frequency. The quantitative results support this

view where operational asset management dictated the primary motivation for undertaking the TRM process. However, there were clear concerns expressed by the focus group that there was a lack of understanding of the external environment in the planning process. This aspect was again supported in the quantitative study in that little relevance was given to the understanding of the environment as a whole. This led the researcher to ask:

*How critical were the transactional/meso- and contextual/macro environments in your analysis, and what critical considerations were considered in your technology selection approach?*

The responses were as follows:

Code 14) Short-term strategic focus: *It was not as critical as the operational environment. Yes, we are aware that environmental issues are important BUT as you are aware our power plants are built to last 40 to 50 years. Thus, there is no way we can upgrade or change our current fleets of power plants to meet potentially future emission targets. It is just way too expensive and thus we look at improving efficiencies as a mechanism of improvements.*

Code 11) Political interference: *For state-owned institutions the role of governments and politics has a huge impact on how we run our business. In many cases the impact can be negative, as politicians have no idea of how to run energy plants... Governments continually interfere in state-owned organisations to a point where it can have huge technology negative impacts on the business and the country.*

The above discussions were extremely robust within the focus group, which led to critical debates and supplementary responses. This was mainly linked to the impact of not considering sufficiently the macro environment in the TRM selection process. The following reactions are highlighted:

Code 14) Short-term strategic focus: *In some cases, it hampered the development of technology as our shareholders (governments et al.) did not*

*always buy in to the technology selection outcomes. This resulted in the lack of funding, skills, and technology adaptation.*

Code 13) Shareholder first: *Shareholders were more likely to fund operational linked improvements rather than medium- to long-term benefits from a technology perspective.*

It was evident from the discussions that the fundamental shortcomings identified played a significant role in the eventual development of TRM. What was apparent to the researcher was that the focus group responses associated with understanding the impacts of both the transactional and contextual environments played a minor role in the TRM process concerning future technology selection. Instead, the operational/microenvironment was considered the most significant in the TRM process. This confirms the findings of the quantitative results where the key emphasis and attention were given to improving operational assets and cost efficiency.

Related to this, the researcher posed a further question associated with the process's time scale and asked the following question:

*How long did your organisation's development roadmapping process take from start to completion of the final product?*

The focus group gave the following responses:

Code 7) Corporate politics – lack of support and Code 16) Sponsor influence: *It generally takes around 12-18 months to come up with the final report. It then took a further 6 months to share with the organisation... In some instances, it took much longer due to the fact that we had poor processes and that it became a 'political ball' within our organisation. This resulted in many cases that the final report never was completed and presented. In many cases because of generally a bottom-up approach the process was started and never completed.*

Code 10) Organisational ignorance: *There is no standard approach to updating the TRM in our organisation. Done in an unstructured manner. Not done annually and seems only to be updated when an executive or technical experts suggest an update.*

Code 12) Return on investment lacking: *A key issues related to the updating of the TRM is that in many cases there is a lack of a clear implementation strategy. In addition, seldom do we apply a robust ROI of the TRM implementation and lack of learning and reflection on the value of the TRM to the organisation. Developing a robust ROI is difficult and seldom done. As mentioned before, this is an area where we lack a robust approach in clearly defining the benefit realisation of the TRM implementation process.*

It was once again evident from the group's responses that the organisation's political environment played a decisive role in the eventual strategic quality of the TRM's final output. However, the overall observation from the group discussion was that the quality of the final TRM document lacked appropriate technological substance.

A further question asked by the researcher related to the ROI of the TRM output was the following:

*How do you go about monitoring, evaluating and reporting the success factors?*

The focus group gave the following responses:

Code 9) Lack of monitoring, reporting and evaluation: *There is no check list on how, when we implement the TRM and thus we are extremely weak in disciplined execution and reporting and evaluation of the TRM benefits. We seldom do surveys with our internal customers and hardly ever with our external customers.*

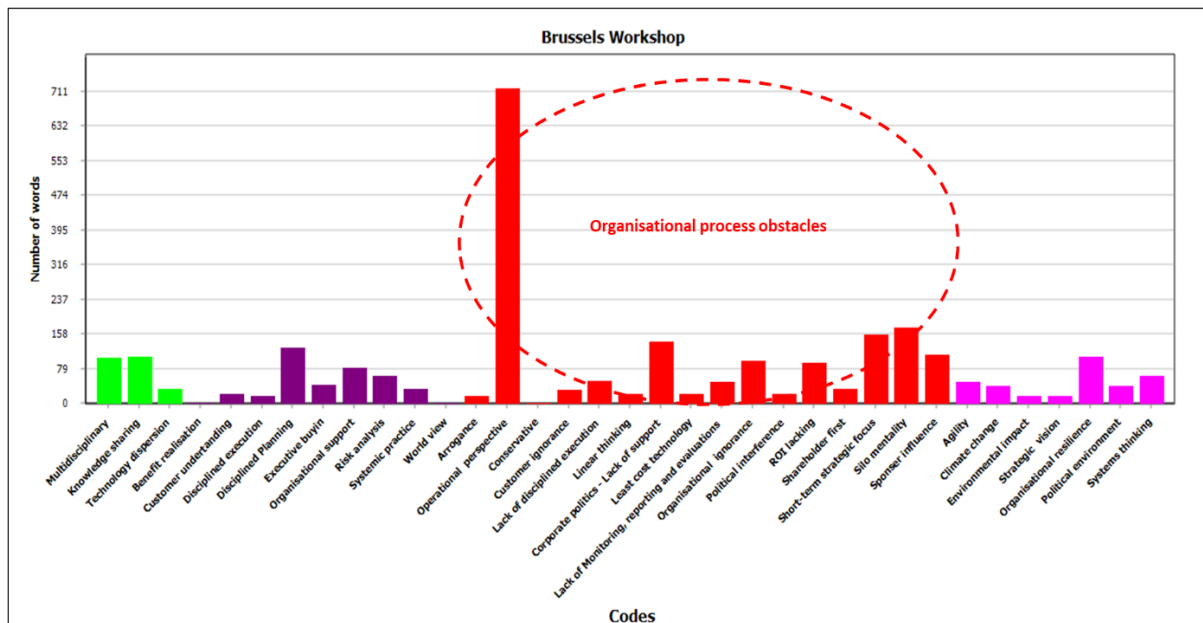
*There is very little focus on developing CSF or KPIs for TRM implementation. Very little CSF's developed TRM implementation... As mentioned, we plan and*

*develop the TRM report and then fail to develop appropriate CSF and ROIs. We are weak in this area and we need to develop process to improve.*

It was clear from the focus group discussions that support, encouragement, and reassurance from organisations were generally lacking, and the group touched on shortcomings that they believed were imperative for the successful implementation of the TRM. The group believed that improving these critical areas would encourage, enable, and increase technology sharing and create a value-added perspective of the TRM.

It is evident from the focus group interactions that the significant shortcomings and obstacles identified in the category of organisational obstacles processes were critical in the subsequent success of the TRM. Figure 5.20 shows the key obstacles and deficiencies described by the group with the obsession of only considering short-term strategic focus and thus driving the operational perspective to a point where there was very little consideration of the external environment.

Other critical obstacles identified were the organisational silo mentality, corporate politics, and the lack of support for the process. A vital and critical hindrance was the issue of sponsor influence in the outcome of the TRM process. See below for a graphical representation of the frequency of 'critical elements of a TRM framework.'



**Figure 5.20: Frequency of coded words for the category 'organisational process obstacles'**

#### 5.4.1.4 Category: Critical constructs

This category addressed the focus group's perception of the critical elements required for a TRM that embraces a system thinking approach. Questions posed to the focus group considered the critical constructs and elements for successfully implementing the TRM process. Figure 5.21 shows the coded frequency (in light purple) for the category 'critical constructs' word count.

The researcher observed during the tea break, and as the workshop was nearing its conclusion, that the participants started to reflect on the discussions, debates, and views given thus far on moving forward. This was an ideal opportunity for the researcher to introduce the question related to the critical constructs:

*When considering the operational issues in your TRM process, what are the key issues and challenges that you need to build into your roadmap with respect to renewables and why?*

The following responses were given:

Code 6) Political environment and Code 7) Systems thinking: *Renewables is something that we need to consider in the long-term. We will be forced sometime in the future through government policy to consider. Key operational considerations that we will have to take into account when considering renewable energy.*

Code 3) Environmental impact: *From an R&D view, improving models to analyse harmonics and resonance issues in wind power plants.*

Code 2) Climate change and Code 5) Organisational resilience: *Assessment of the impact of initiatives and other measures to promote large scale introduction.*

Code 2) Climate change: *In terms of the long-term future we then look at the introduction of renewables as climate change will be something that we need to consider in the next 10 to 20 yrs. We cannot consider it now as we have extremely expensive assets and their life time is around 40 to 60 years.*

It was evident from the discussions that climate change and environmental impacts seemed to play a lesser role in determining the technology futures of this group. The observation was made that the codes 'climate change' and 'environmental impacts' were perceived to show minor influence in the TRM process. This was confirmed in the quantitative study, where social impact and environmental sustainability responses were regarded as minor considerations. The following question was posed:

*How critical was the contextual environment in your analysis, and what macro considerations were considered?*

The following response was given:

Code 6) Political environment: *Governments continually interfere in state-owned organisations to a point where it can have huge technology negative impact on the business and the country.*

The group was adamant that the continual demands of governments and the political interference on regulatory requirements, and thus on their business, made it at times extremely difficult to operate sustainably. This resulted in ongoing political battles, which significantly impacted the organisation's operating model and consequently impacted its technology strategy.

It was observed that when comparing the quantitative results, political alignment/environment was not considered an important factor. This indicated a divergence of thinking between the two data sets. The researcher suggests that this changing mindset resulted from the group dynamics within the workshop, where the political environment was seen as a central driver in future technologies' development. However, the quantitative data revealed that regulatory requirements were considered key drivers in the TRM process, highlighting the focus on the business's operational aspects.

The closing question at the workshop was:

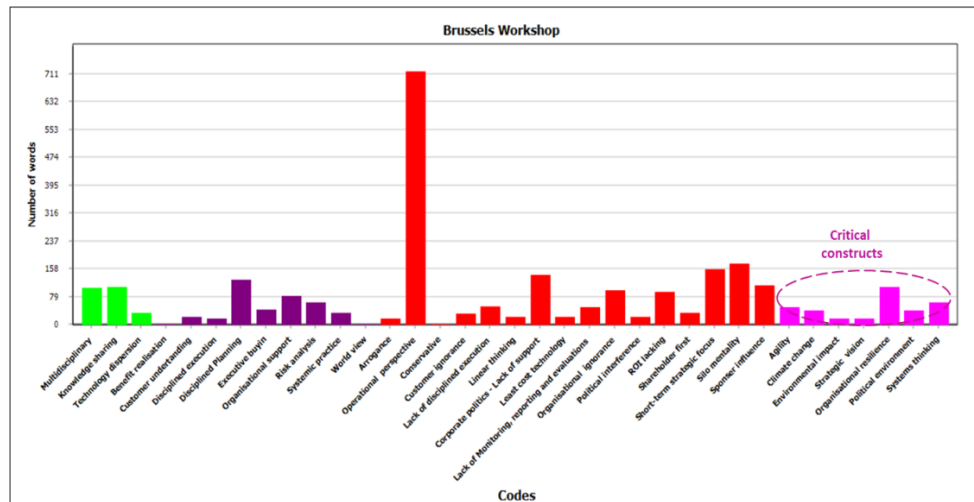
*Do you believe there was value in undertaking the TRM?*

The following responses from the focus group indicated strongly that all participants felt that the TRM process was indeed value-adding, even noting the current obstructions and shortcomings:

Code 7) Systems thinking: *Yes, we believe there is major benefit to organisations in undertaking the TRM. However, you must note that we are part of the process in developing the TRM by considering the bigger picture and thus believe it's an imperative.*

Code 1) Agility: *It creates value from an efficiency perspective, if given the organisations a view of what technology they need to consider in the future as it focuses on operational performance and thus has a huge impact on the financial aspect on the business regarding financial savings and improved performance.*

It was apparent from the focus group interactions for this category that organisational resilience, systems thinking and agility were highlighted as necessary in terms of long-term technological sustainability. A further area considered was the influence of the political environment on long-term technology strategies and the resultant impact on organisational decision making. See below for a graphical representation of the frequency of 'critical constructs'.



**Figure 5.21: Frequency of coded words for the category 'critical constructs'**

In summary, the Brussels qualitative analysis revealed that some codes were unique to specific categories. The Brussels focus group results indicated that the category 'Organisational process obstacles' had by far the highest code frequency (~60%) and were an area of intense focus group debate. The associated codes with the highest frequency were; operational perspective, silo mentality, short-term strategic focus, corporate politics, and sponsor influence. These were significant obstacles and impediments to the technology roadmapping process's ultimate success.

In addition, embedded within the same category, the codes of organisational ignorance and the lack of appropriate Return on Investment (ROI) were also considered vital shortcomings in the ultimate implementation of the roadmap. These results are imperative drivers in understanding and developing a conceptual framework.

Under the category 'Critical elements', disciplined planning was also considered an

essential process with a code frequency of 6.1% in successfully developing the roadmapping process. The focus group participants also placed value and importance on knowledge sharing (code frequency 5.1%), multi-disciplinary (code frequency 4.1%) and organisational resilience (code frequency 4.1%), which were linked to absorptive capacity and critical constructs, respectively. Disciplined planning in the roadmapping process and knowledge sharing were highlighted, which are vital in developing a learning organisation culture.

The codes related to systemic practice, strategic vision, disciplined execution, and customer understanding all had a code frequency of 1.0%, suggesting a lack of consideration or importance in this area from the focus group participants. This further suggests why the intense focus on internal operational perspective and the seeming lack of thought to systemic understanding and practice. These are significant considerations that organisations need to reflect on in developing technology roadmaps and are central and vital for organisational and technological sustainability. The results of this category highlighted the key areas that are linked to RQ4 and critical drivers in the construction of a responsive technology framework.

In addition, the Brussels focus group workshop and the quantitative survey results mostly indicated a convergence of views. However, diverging views regarding political alignment and environment were observed, indicating a change in thinking between the two data sets. The results highlighted several critical areas of concern and issues in the roadmapping process regarding the primary research question posed in this study.

#### *5.4.2 Berlin focus group workshop*

This section presents the results of the focus group workshop held in Berlin 18 months after the Brussels workshop. As described in Section 5.2, 25 IRO members participated in this focus group workshop. The make-up of the participant's industries they represented were 32.0% from Electricity R&D organisations, 60.0% from Electricity Power Utilities, 4.0% from electricity-related NGOs, and 4.0% from universities, which was a relatively broad representation from across the globe.

Some 34 codes were developed in the thematic analysis, and the respective codes linked to the categories, which aligned with the research questions of this thesis (Table 5.4). Appendix 8 shows the focus group responses, and Appendix 9 the coded frequencies associated with each category.

**Table 5.4: Berlin focus group themes, categories and codes**

Themes	Category	Codes
Organisational innovative capacity	Absorptive capacity	<ul style="list-style-type: none"> <li>• Knowledge sharing</li> <li>• Multidisciplinary</li> <li>• Technology dispersion</li> </ul>
Business leadership practice	Critical Elements of a TRM Framework	<ul style="list-style-type: none"> <li>• World view</li> <li>• Risk analysis</li> <li>• Executive buyin</li> <li>• Disciplined planning</li> <li>• Disciplined execution</li> <li>• Benefit realisation</li> <li>• Systemic practice</li> <li>• Organisational support</li> <li>• Customer understanding</li> </ul>
Organisational behaviour	Organisational Process Obstacles	<ul style="list-style-type: none"> <li>• Operational perspective</li> <li>• Lack of ecosystem understanding</li> <li>• Shareholder first</li> <li>• Short-term focus</li> <li>• Conservative</li> <li>• Arrogant</li> <li>• Customer ignorance</li> <li>• Sponser influence</li> <li>• Organisational ignorance</li> <li>• Corporate politics - Lack of support</li> <li>• Least cost technology</li> <li>• Political interference</li> <li>• Lack of disciplined execution</li> <li>• Lack of appropriate ROI</li> <li>• Lack of MRE</li> </ul>
Systems thinking prerequisites	Critical constructs	<ul style="list-style-type: none"> <li>• Ecosystem understanding</li> <li>• Organisational resilience</li> <li>• Agility</li> <li>• Political environment</li> <li>• Climate change</li> <li>• Environmental impact</li> <li>• Systems thinking/engineering</li> </ul>

#### 5.4.2.1 Category: Absorptive capacity

Figure 5.22 shows the coded frequency of words per code with specific reference for the category 'absorptive capacity'. The questions posed to the focus group were related to some of the key strategic factors that influenced their approach to technology roadmapping outcomes

According to the focus group's comments and responses, an organisation's ability to recognise future technology value was mostly clouded by short-term shareholder goals and targets. This was further supported by the quantitative Berlin results, which indicated that short and medium-term planning shaped the roadmapping process. However, it was seen as critical where technology could solve short-term and immediate operational issues. This was highlighted by the group's response to the following question:

*What was the resultant impact of the meso-/transactional environment on the technology selection process?*

Code 1) Knowledge sharing and Code 3): Technology dispersion: *Identifying technologies for business improvement processes in terms of sustainable supply to our customers... In addition, the economic aspects are critical in terms of organisational sustainability and technology adaptation.*

This was in line with the results of the Berlin quantitative survey, where a marked increase and convergence in the importance of customers understanding and political and regulatory requirements was seen.

The above discussion led to the researcher asking the following question in terms of TRM uptake into the organisations:

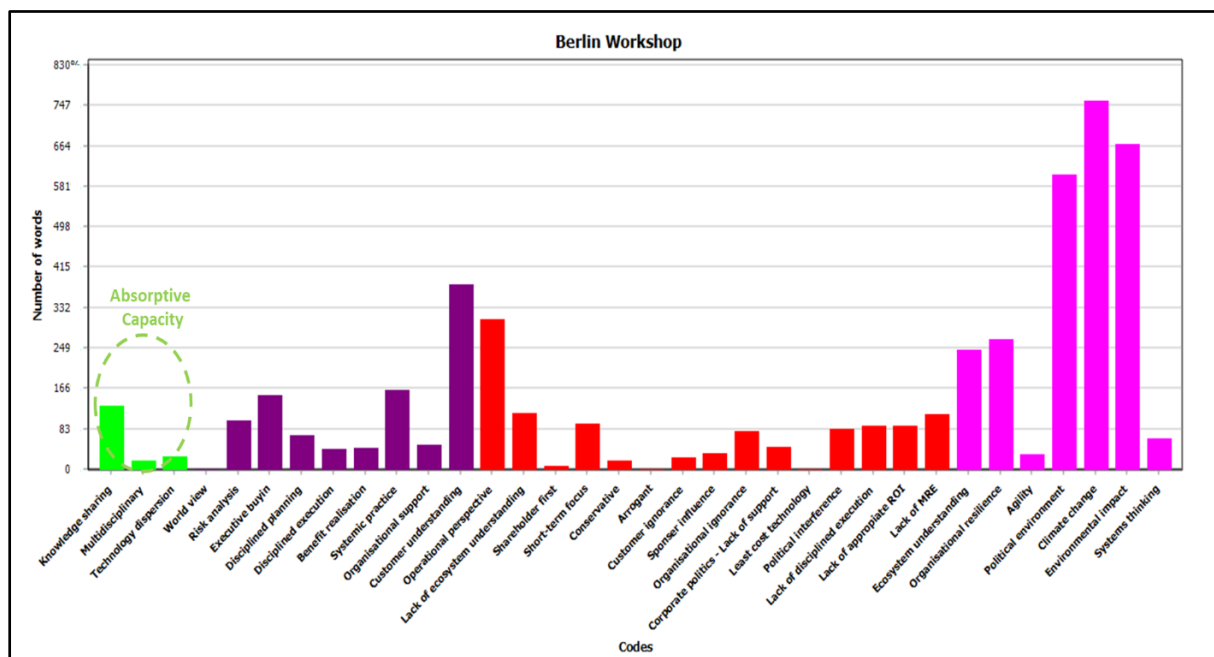
*Was the TRM process integrated into other internal strategies, and if so, how were they interrelated?*

The following are the comments:

Code 1) Knowledge sharing: *It was seldom integrated fully into the organisations business mode. However, recently this is slowly changing in those issues related to technologies and the approach to energy transition to clean technologies is now becoming a key aspect in our business strategic plan and thus operating model.*

Code 1) Knowledge sharing and Code 2) Multidisciplinary: *It also has the potential to develop new innovative products and at the same create engineering and scientific skills and produces products that create value to the business... used in the organisation to utilise the outputs of the TRM in its strategy for the future.*

The above comments are closely aligned with the feedback results from the quantitative study, where there was a strong alignment with the improved innovation culture of the organisation, increased entrepreneurial culture, enhanced R&D capability and funding and improved executive support and buy-in.



**Figure 5.22: The frequency of coded words for the category 'absorptive capacity'**

It became clear from the group discussions regarding the category 'absorptive capacity' that it was seen as critical in terms of the TRM uptake within organisational strategies. The group further elaborated and confirmed the importance of knowledge sharing and the ability to identify, assimilate, transform, and use technological knowledge, research, and practice for an organisation to be agile, adaptable, and

sustainable. The focus group saw the 'knowledge-sharing' code as the most important aspect under this category.

#### 5.4.2.2 Category: Critical Elements of a TRM Framework

A question posed to the focus group was associated with some of the key strategic factors that influenced the group's approach to business leadership styles and organisational culture related to the TRM process. Figure 5.23 shows the coded frequency for the word count for the category 'critical elements of a TRM framework'. The codes are shown in purple.

Discussions around leadership and culture as it pertains to the TRM process, acceptance, and approval covered many significant views and considerations. The researcher started the discussion by asking the group about the initial planning process related to the sponsoring and planning phases of the TRM. The following responses from the group were given:

Code 3) Disciplined execution and Code 4) Organisational support: *The difficulty at first was those resources (both funding and people) were not appropriately allocated, resulting in time delays... and as such, the process was hampered. This resulted in the technology roadmap not always been fully being accepted by various parts of the business.*

Code 5) Executive buy-in: *It has been noted that in some cases, it has been initiated by the CEO and executive. This has been mostly due to political pressure from national governments and the need to consider issues such as climate change and environmental issues.*

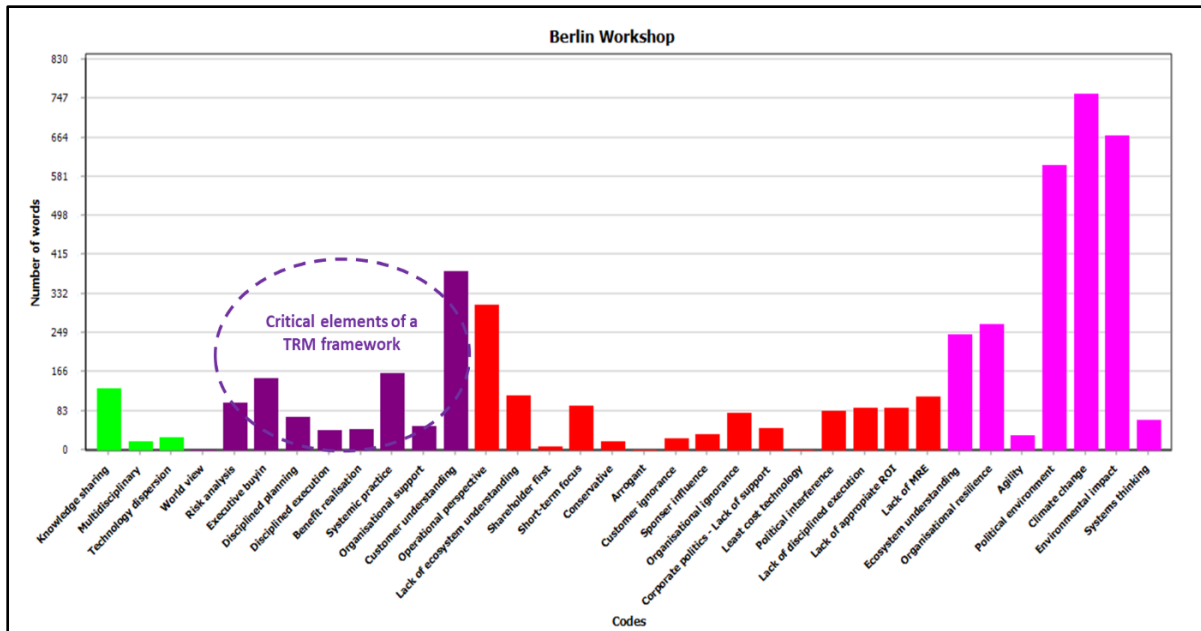
Code 5) Executive buy-in: *This is clearly headed up by our executive CEO etc., and the TRM is critical to the sustainability of our business and meeting our customer's needs.*

Code 4) Organisational support and Code 5) Executive buy-in: *The difficulty at first was that resources (both funding and people) were not appropriately allocated, resulting in time delays.... In cases where the CEO and executive supported the process, there was more acceptance and better integration across the business. This resulted in improved strategic value to the business and the line divisions.*

Code 3) Disciplined execution: *Our organisation which is an R&D only business, structures were well developed in terms of the process. There was a high-level commitment which made the process that much easier to manage in terms of our time frames and final outputs.*

It was observed from the discussion and the responses from the focus group that executive backing, supportive management, reassurance, and encouragement from management had to exist in the initial planning phase for the TRM to ensure adequate organisational support. These observations again aligned with the quantitative survey undertaken where executive support and buy-in were critical in the ultimate success of the roadmapping process.

Figure 5.23 shows customer understanding as the most important, followed by systemic practice and executive buy-in as the most crucial codes in this category. Important to note is that executive buy-in is a central precursor of disciplined planning, as shown in Figure 5.23, as the third most crucial code.



**Figure 5.23: The frequency of coded words for the category 'critical elements of a TRM framework'**

The focus group's insights and views on applying a systemic approach in the development of the TRM were interesting. This was based on the researcher's question:

*What was the resultant impact of the operational, transactional and contextual environments on the technology selection process?*

The following responses followed:

Code 8) Systemic practice: *Shareholders are more likely to fund operational linked improvements rather than medium- to long-term benefits from a technology perspective... However, there is a move for shareholders to see the importance of adapting business models to that of reducing carbon emissions...however, we note that this process has started to change due to the importance of appropriate clean technologies in the future.*

Code 8) Systemic practice: *Meeting regulatory requirements are important. Reduce carbon emissions, which means identifying appropriate alternative*

*source of green energy e.g., renewables, nuclear etc. Reduce pollution emissions.*

Code 8) Systemic practice and Code 9) World view: *Contextual environment is becoming an important factor in technology selection in terms of overall environmental sustainability, political acceptance, and social requirements.*

It was evident from the discussions and deliberations that understanding the ecosystem (operational, transactional, and contextual environments) is imperative in the TRM approach to future technology selection and adaptation. In particular, the area most emphasised by the group was the contextual environment in terms of relating much of their discussion to the social, technological, economic, environmental, and political arena.

According to the focus group's insights and responses, customer-centricity-related consideration was critical in developing future customer value technologies. Thus, understanding the key customer attributes was vital to the TRM design and approach. As seen in Figure 5.23, the code customer 'understanding' was rated the most in this category. The frequency of this code was more than double that of the next highest ('executive buy-in' code). Several critical opinions were raised by the group concerning customer understanding and are as follows:

Code 2) Customer understanding: *The application of affordable electrification technologies in rural regions in terms of increasing access to our potential customers... Customer services offered by non-traditional actors might also impact the traditional business models... Customer pressure on more reliable quality of supply and more affordable electricity.*

Code 2) Customer understanding: *Efficiency Targets - Government is promoting energy efficiency and conservation, e.g., on guidelines and incentives for buildings, air-conditioning, renewables. Electrification Targets - 90% of SA electrified by 2030. 10% will be non-conventional off-grid solutions, i.e. micro grids.*

Code 2) Customer understanding: *In the R&D institutes, customers were involved in the process. Mainly at the end of process and feedback on the final TRM report.*

It was evident from the group's discussion that customer understanding was a significant component in the value chain of consideration in the TRM process and outcomes. The group viewed customer interactions as contact points in which the organisation and customer both acquired and distributed knowledge in a shared and cooperative manner in the best interests of both the customer and the organisation.

The analysis has also shown that in the initial planning of the TRM process, customer understanding, systems thinking, and executive buy-in are imperatives to consider in developing the TRM process and approach. These findings align with the quantitative survey results, highlighting customers, social accountability, political alignment, executive support, and buy-in as critical pointers for successfully applying the roadmapping process.

#### 5.4.2.3 Category: Organisational process obstacles

This category addressed the focus group's perception of the impediments and shortcomings experienced in their organisation during the TRM development. Questions posed to the focus group were concerned with the key obstacles, impediments, and shortcomings experienced during the TRM development process. Figure 5.24 shows the coded frequency (in red) for the category 'organisational process obstacles' word count.

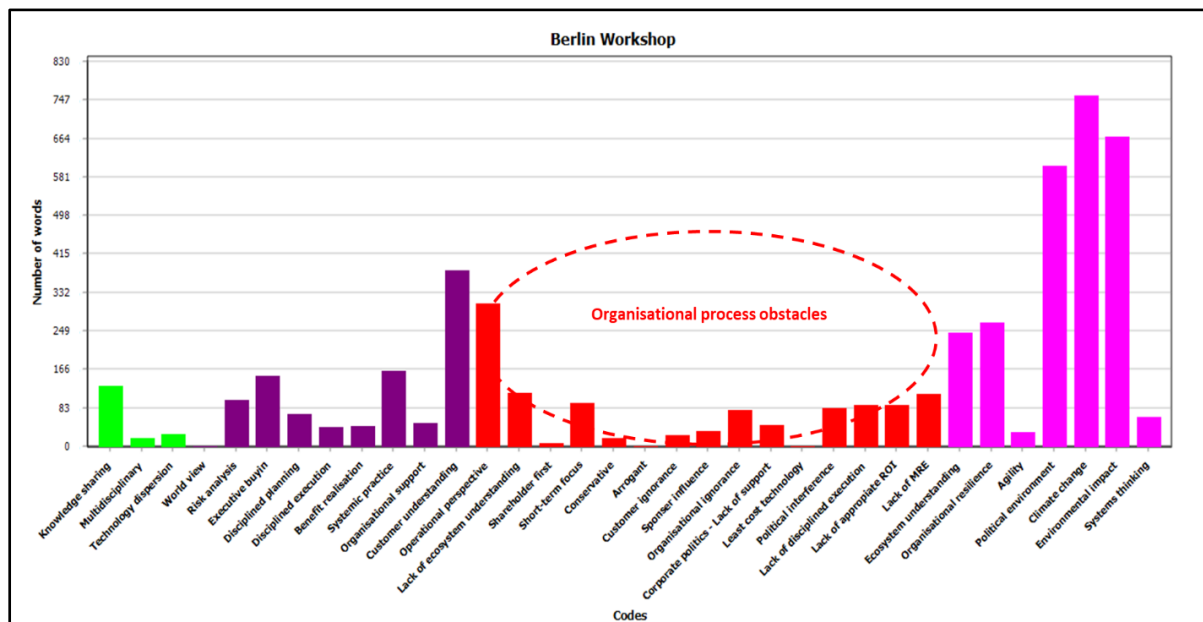
The focus group reflected and exchanged several ideas and information around the issues of organisational process obstacles. It became apparent that the group exchanged ideas and information, facilitating many critical issues when questioned. For example, the first question raised by the researcher was:

*Who sponsored the development of TRM?*

As a result, the focus group had the following comments:

Code 2) Lack of understanding and Code 12) Political interference: *It is a bottom-up approach developed by technologists in support of future technology developments... It has been noted that in some cases it has been initiated by the CEO and executive. This has been mostly due to political pressure from national governments and the need to consider issues such as climate change and environmental issues... The structures were initially not well developed and as such the process was hampered.*

Code 12) Political interference: *Governments continually interfere in state-owned organisations to a point where it can have huge technology negative impacts on the business and the country.*



**Figure 5.24: The frequency of coded words for the category 'organisational process obstacles'**

The group's feedback on the lack of understanding and political interference was identified as crucial obstacles to the TRM development process. The group suggested that the TRM process was disadvantaged from the start because the process did not always have executive support and was considered flawed due to ongoing political

meddling. This was particularly relevant in state-owned organisations. The quantitative survey also identified this aspect, where political alignment was a critical variable.

Following on from the above discussion, the following question raised by the researcher was:

*What were the main strategic factors that influenced the approach to technology roadmapping outcomes in your organisation?*

Code 1) Operational perspective and Code 4) Short-term focus: *Operational issues and plant flexibility are key to the survival of our business. Asset management is key in terms of quality of supply. So, one of our key drivers is an approach to roadmapping that is operational performance and thus asset management... Linked to this is the driver of regulatory requirements. This is linked to regulatory requirements related to environmental protection.*

Code 1) Operational perspective: *A strong push in the way we look at future technologies that are sustainable and being able to meet the requirements of network integration. In addition, making power generation affordable and reliable at the same time.*

The above responses were then followed by a further question:

*What was the resultant impact of the operational drivers on the technology selection process?*

Code 2) Lack of understanding and Code 4) Short-term focus: *In some cases, it hampered the development of technology as our shareholders did not always buy in to the technology selection outcomes. This resulted in the lack of funding, skills, and technology adaption. Shareholders are more likely to fund operational-linked improvements than medium- to long-term benefits from a technology perspective.*

Code 1) *Operational perspective* Code 9) *Organisational ignorance: The operational side R&D in some organisations would be considered a cost and not a value, and thus had a major impact on the funding model of technology in the organisation. R&D was generally seen as a cost not a value.*

The focus group's perception was that too much emphasis was placed on the organisation's short-term goals, which led to significantly more emphasis on the operational side of the business. As shown in Figure 5.24, the code 'operational perspective' frequency is more than double that of the following highest code, thus showing the importance the focus group has placed on the code.

In addition, the group felt that the continued obsession with organisations focusing predominantly on operational performance could lead to a long-term decline in future technologies' strategic value and organisational sustainability. This view correlates well with the quantitative results in that the most overriding focus was on the operational side of the business, suggesting that short-term goals were still the main priority in the selection process.

The researcher then further explored an approach with the group based on the outcomes obtained from the previous question. The question posed to the group was:

*How has your organisation's executive support influenced the success or failure of the TRM process and implementation?*

Code 8) *Sponsor influence* and Code 10) *Corporate politics – Lack of support: In some cases, executives tend only to use the TRM for their own gain and once the final report is done and presented, executives tend to move on to their next project.*

Linked to the above response, the following comments from the focus group indicated the impact of the lack of support for the TRM rollout process. This was due to the lack of an appropriate planning and execution strategy. The TRM implementation plan

lacked the capability to monitor, evaluate, and report critical key indicators. This can be seen from the comments below:

*Code 13) Lack of disciplined execution: There is still a lack of disciplined execution process of the TRM, and this is due to the fact that there is no clear implementation plan along with the appropriate funding mechanisms.*

*Code 13) Lack of disciplined execution and Code 15) Lack of monitoring, reporting and evaluation (MRE): Generally, we have specific CSF for projects however, not for the entire TRM process in terms of implementation and execution... As mentioned before, this is an area where we lack a robust approach in clearly defining the benefit realisation of the TRM implementation process ... So, there is very little focus on developing CSF or KPIs for TRM implementation.*

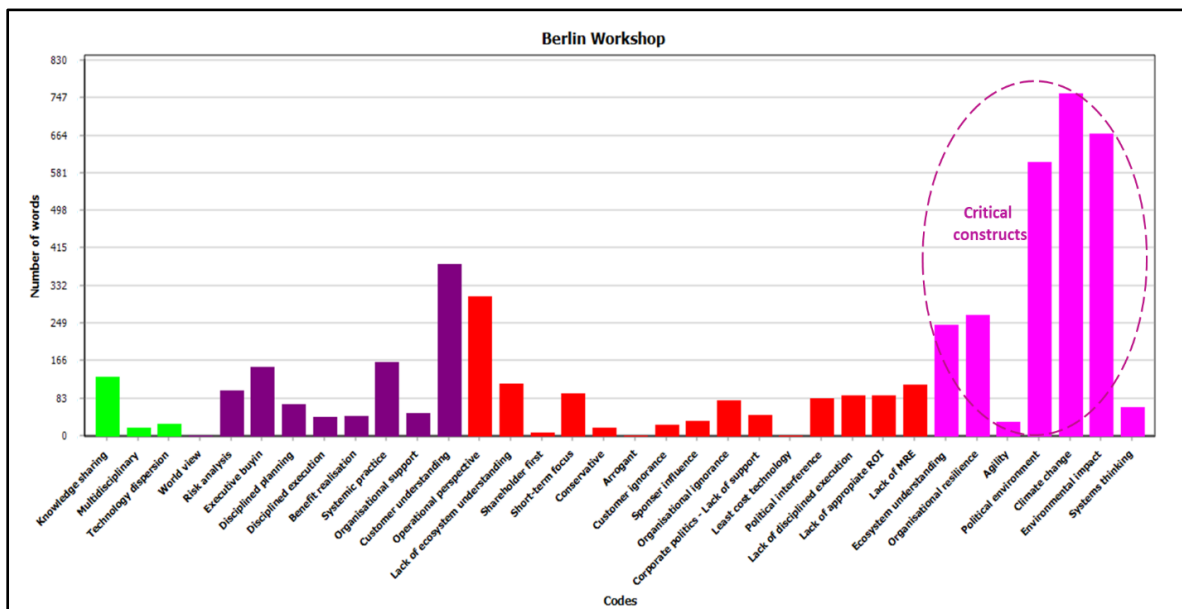
*Code 14) Lack of an appropriate ROI: Developing a robust ROI is difficult and seldom done. There is no check list on how and when we implement the TRM and thus we are extremely weak in disciplined execution and reporting and evaluation of the TRM benefits.*

It was apparent from the group discussions that lack of planning, disciplined execution, lack of support, and political interference were major obstacles encountered in organisations. The group felt that these shortcomings had a significant impact on the successful implementation of the TRM. The group believed that improving these critical areas would encourage, enable, and increase technology sharing and create a value-added perspective of the TRM.

It is evident from the focus group interactions that one of the significant areas of concern in this category was the preoccupation with the short-term strategic focus, and as a result, the primary focus was on short-term operational issues. The group felt this was a fundamental shortcoming as the business failed to fully comprehend the unintended consequences of its decisions of not fully considering the changing state of the ecosystem.

#### 5.4.2.4 Category: Critical constructs

This category addressed the focus group's perception of the critical elements essential for a TRM process to embrace systems thinking. Questions posed to the focus group considered the critical constructs and elements for successfully implementing the TRM process. Figure 5.25 shows the coded frequency (in light purple) for the category critical constructs.



**Figure 5.25: The frequency of coded words for the category 'critical constructs'**

The codes considered significant for this category were climate change, environmental impact, ecosystem understanding, political environment and organisational resilience. In addition, one could consider the combination of ecosystem understanding and systems thinking as a grouping. The codes, climate change, environmental impact and political environment converged with the quantitative survey data in that political alignment, social accountability, and environmental sustainability were crucial drivers in factors that influenced the TRM process and outcomes.

The group approached the questions concerning the critical constructs as a guiding principle for an improved TRM approach that was thought-provoking. It became

evident that the group exchanged various ideas and thinking, allowing for an interesting exchange of information and comments. For example, the first question asked was:

*Who sponsored the development of TRM?*

This was followed up with the question:

*How critical was the contextual environment in your analysis, and what macro considerations were taken into account?*

The following comments were given:

Code 1) Ecosystem understanding, Code 2) Organisational resilience and Code 7) Systems thinking: *This is clearly headed up by our executive CEO and the TRM is critical to the sustainability of our business and meeting our customers' needs... In many cases the impact can be political demands and social demands, which greatly impact the way we undertake our TRM analysis.*

Code 1) Ecosystem understanding: *In all cases the exploratory approach was used, i.e. scenarios were developed as possible futures. These futures were developed in-house; however, at times they differed from the organisational scenario based on the scenarios developed by the technical experts in most cases.*

Based on the above responses the researcher then followed up with a supplementary question:

*What was the resultant impact of the macro drivers on the technology selection process?*

The following responses were given:

Code 5) Climate change: *What is becoming a key driver as well is related to carbon emissions and the impact on climate change. So, we are now looking at technologies that would reduce and minimise carbon emissions. Thus, all aspects of renewables will be key drivers but at present we are looking a hybrid approach and that will still have to include coal (fossil fuels) and nuclear... there is a move for shareholders to see the importance of adapting business models to that of reducing carbon emissions.*

Code 2) Organisational resilience, Code 4) Political environment and Code 5) Climate change: *National political pressure (government interference) is becoming a major issue and we have to react to this. This is in terms of government generation requirements in terms of national global climate signatories that our government has signed and approved regarding carbon emissions. Clearly the aspect of political pressure both from a national, as well as a global, perspective from a carbon emission view is becoming a key driver to businesses that use coal and fossil fuels to generate electricity.*

Code 6) Environmental impact: *Customers and pressure group are also significantly impacting the way we view future generation and thus technology adaptation for the future.*

It became clear from the focus group's responses that various key codes were highlighted for successfully executing a TRM process. The focus group were undivided in their views and comments that the five codes identified (climate change, environmental impact, political environment, organisational resilience, and ecosystem understanding) were critical considerations in developing a robust organisational TRM. The researcher then posed a further question related to the above responses:

*When considering the operational issues in your TRM process, what are the key issues and challenges that you need to build into your roadmap with respect to renewables and why?*

Code 2) Organisational resilience: *Need to develop a hybrid approach as we cannot just shut down our fossil fuel plants. There would be unintended consequences of this approach and as such, we need to consider the risks and roll out the transition programme accordingly.*

The response from the focus group was interesting in that the group stated that even though climate change and environmental impacts are critical vital drivers, the short-term impacts could potentially have negative consequences for both power utilities and the fossil fuel community. Thus, the comment '*develop a hybrid approach*' was emphasised in a gradual transition to more climate-friendly technologies.

The analysis showed a good alignment between the quantitative and qualitative results for the Berlin focus group in social accountability, environmental sustainability, ecosystem understanding and political alignment. A significant additional response which evolved from the focus group responses was the emergence of organisational resilience as a critical consideration in the roadmapping planning process.

In summary, the Berlin focus group facilitated many ideas and information sharing, resulting in a highly stimulating process of critical thinking and discussions. The researcher observed during the facilitation process that the group dynamics revealed, in most cases, similarities and, at times, differences. Good alignment was seen between the quantitative and the Berlin focus group results, indicating a general convergence of results from both datasets.

The overall focus group responses showed that the category 'critical constructs' had the highest code frequency of ~40%, with climate change, environmental impact, political environment, customer understanding, organisational resilience and ecosystem understanding being the most dominant codes. The code 'operational perspective' was also considered an important driver.

The results and responses from the Berlin workshop highlighted and identified critical drivers of importance in the approach to technology roadmapping, which aligned with this thesis's objective and research questions. An essential outcome of the focus group workshop results was that the group accepted the need for organisations to

intensify their efforts better understand the ecosystem's relationships, i.e. environmental impact, political environment, customer understanding and organisational resilience.

The results indicated that a deep understanding of the political environment, environmental and climate change impacts, organisational resilience, customer understanding, and knowledge sharing would significantly enhance the TRM process. The focus on operational perspectives was still evident in maintaining current technical operations. However, there was a view that more was required in the monitoring, reporting and evaluating approach in the roadmapping implementation phase.

This highlights the group thinking change to a more holistic consideration. However, this could be a reactive approach caused by the increasing pressure and demands from national and global political pressures. These key outcomes align with the research questions and are substantial inputs were considered in developing the conceptual framework.

#### *5.4.3 Brussels and Berlin focus group comparative analysis*

This section will undertake a comparative analysis between the Brussels and Berlin focus group datasets. The results from the qualitative phase of this study provided the researcher with the results of the two focus group workshops, which examined specific categories and codes. By an in-depth analysis of the two focus group workshops, the data gathering (i.e. the group discussions, observations, and questionnaires) allowed the researcher to study the key variables considered critical for the development of technology roadmaps.

The analysis of the codes and categories has been shown to differ from case to case and is fundamental in any qualitative study (Creswell and Plano Clark, 2017:59) as was the case with the Brussels and Berlin datasets. In addition, the sequence of the two focus group workshops over the 18 months provided the researcher with comprehensive insights into the critical components that can be considered as prerequisites in developing a technology roadmapping framework. The analysis

examines the specific categories and related codes, and secondly, the analysis examines the integrated view of the combined qualitative study from the two datasets.

#### 5.4.3.1 Comparative analysis

Figure 5.26 shows the frequency of codes for the Brussels and Berlin focus group workshops. From the figure, it can be seen that the Brussels focus group workshop indicated that the category 'Organisational process obstacles' had the highest total code frequency of 44.9% and 59.0% of the total coded dataset. Within the focus group, this category was an area of intense discussion and debate during the workshop.

The dominant codes within this category, 'operational perspective', 'organisation silo mentality', 'short-term strategic focus', 'corporate politics', and 'sponsor influence' codes. These were deemed significant obstacles and impediments in the technology roadmapping process's ultimate success. In addition, embedded within the same category, the codes of 'organisational ignorance' and the 'lack of appropriate Return on Investment (ROI)' were also considered vital shortcomings in the ultimate implementation of the roadmap. The category 'critical elements' made up the highest code frequency (15.4%), followed by 'critical constructs' (14.2%) and 'absorptive capacity' with 11.2%.

The codes related to 'systemic practice', 'strategic vision', 'disciplined execution', and 'customer understanding' all had a code frequency of 2.2%, indicating a lack of consideration or importance in this area from the focus group participants. This indicated the intense focus on internal management operations and the seeming lack of consideration for systemic understanding and practice. These are significant considerations that organisations need to reflect on in developing technology roadmaps and are central and vital for organisational and technological sustainability.

In contrast to the Brussels results, the Berlin results (Figure 5.26) indicate a significantly different result. Unlike the Brussels results, where the code 'operational perspectives' and the category 'organisational process obstacles' dominated, the Berlin results show the highest code frequency in the category 'critical constructs' of

36.9% and 39.4% of the total coded dataset. The dominant codes were 'climate change', 'environmental impact', 'political environment', 'organisational resilience', and 'ecosystem system understanding'.

An interesting observation in the Berlin results indicates a decline in the frequency of ~18% in the code 'operational perspective', from 26.5% recorded at the Brussels workshop to 8.8% at the Berlin workshop. This implies the changing trend from the Berlin focus group participants over the 18 month period, from a predominantly silo mentality and internal operational perspective to a more outward perspective and external view of the ecosystem. This is a significant result in that a clear divergence of results were noted from the Brussels meeting and the Berlin meeting for this category.

The researcher suggests that this change in Berlin's responses could be due to the increased focus on global climate change impacts, which could be attributed to the Conference of Parties (COP) meetings held between the two focus group workshops, COP 24 and COP 25. The outcomes of the COP meetings were strongly focused on electricity utilities' emissions and the need for them to start actioning appropriate technologies in the transition to a greener economy.

In addition, the COP outcomes also requested governments to take more decisive action against these organisations through policy interventions and other mechanisms to intensify appropriate technology transitions (KPMG, 2019:16). Thus, the researcher proposes that the climate change intervention and the changing political environment were key drivers in the ultimate changing trend in the Berlin results, as seen by the three dominant codes shown in Figure 5.26.

The comparative analysis also indicated a diverging result between the two focus group workshops when analysing the 'critical elements' category. In the Brussels results, the dominant code in this category was 'disciplined planning' of 6.1% (an operational process), which was seen as important in the roadmapping process. However, the Berlin results for this category indicated a move away from a predominately internal thinking approach to a more outward ecosystem consideration, as shown by the fact that 'customer understanding' and 'systemic practice' were the

two top code frequencies in this category of ~14%. The divergence of results for this category from the two focus group workshops was a significant contribution in developing a conceptual framework and resolving the key research questions of this thesis.

An important outcome of the Berlin workshop was that the group overwhelmingly accepted the need better to understand the relationships and interrelationships in their respective organisations. The group strongly believed that a deep understanding of climate change, understanding the political environment and environmental impact, customer understanding, and organisational resilience would significantly enhance the TRM process, and thus increase organisational sustainability.

This contrasts with the Brussels group, which was predominantly internally focused, with operational perspectives dominating the code frequency. The focus on operational perspectives in the Berlin results was still evident in maintaining current technical operations. However, there was a view that ecosystem understanding was still problematic in the roadmapping process and that more was required in the monitoring, reporting, and evaluating aspects in the roadmapping implementation phase.

Figure 5.27 shows the word cloud for Brussels and Berlin, highlighting the divergent thinking between the two focus groups. However, the researcher suggests that this change in the thinking from the Berlin dataset could be due to a reactive action initiated by the increasing pressure and demands from the Conference of Parties (COP) outcomes. The results from this comparative study significantly contributed to the approach in developing a conceptual roadmapping framework and in answering the research questions of this thesis.

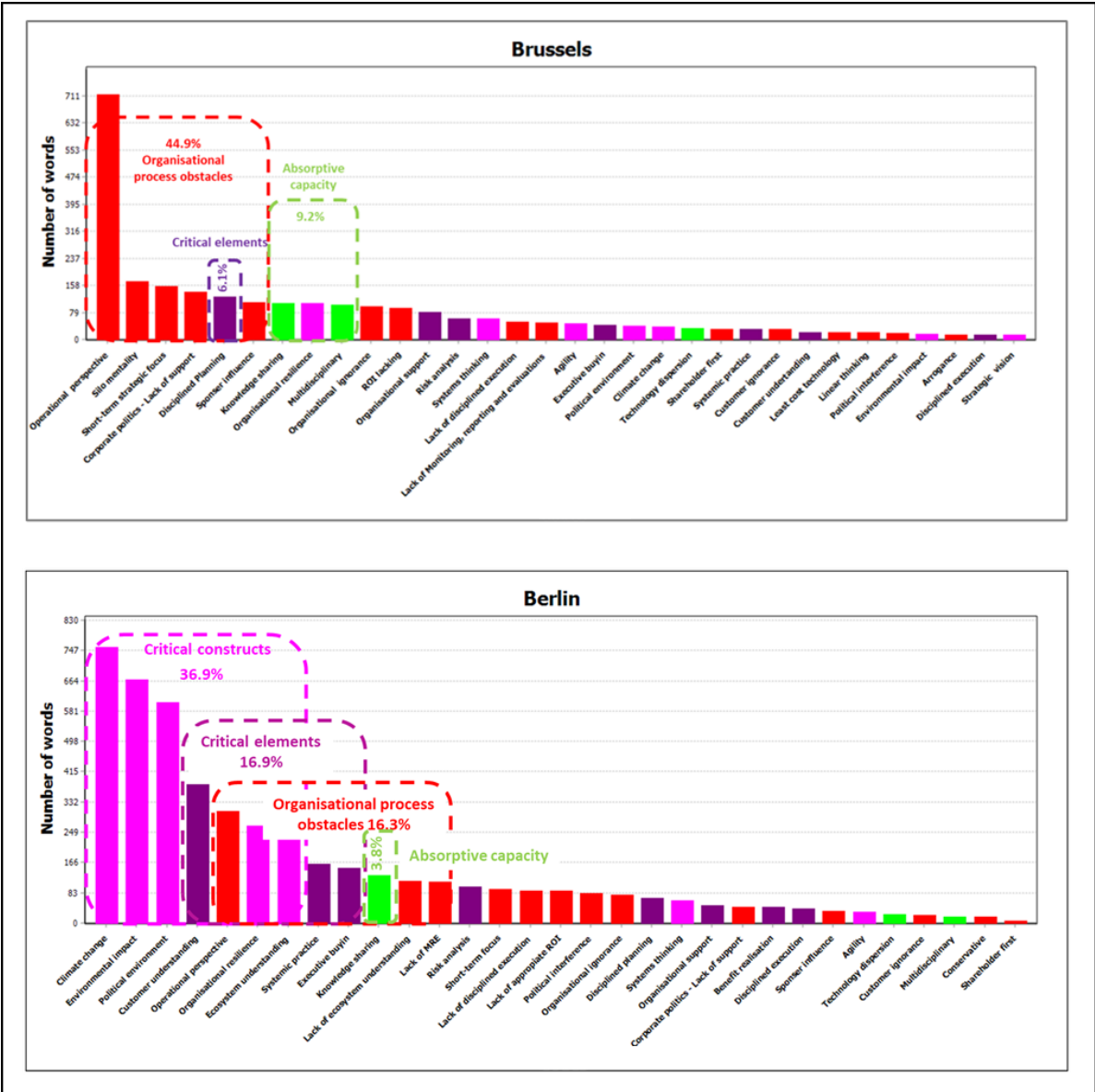


Figure 5.26: Frequency of codes from the Brussels and Berlin workshops



**Figure 5.27: Word cloud of codes for the Brussels and Berlin workshops**

5.4.4 Qualitative survey 2021

A final focus group workshop was arranged and planned for the IRO members for May 2021. However, in 2020 the global pandemic of COVID-19 caused lockdowns worldwide, which had a major impact globally, and as such, the planned workshop

was cancelled. As a result of the global lockdown, the researcher then applied an alternative approach in the form of a survey.

The same themes and categories developed for the workshops were applied in this analysis. This meant that consistency was applied throughout the quantitative analysis, lending to a more reliable comparative analysis of the quantitative data. The four themes, each with an associated category and codes, were:

1. Organisational innovative capacity.
2. Business leadership practice.
3. Organisational behaviour.
4. Systems thinking prerequisites.

Some 30 codes were developed in the thematic analysis, and the respective codes were linked to the categories, which aligned with the research questions of this thesis (Table 5.5). The survey questionnaire is shown in Appendix 10, and the results of the survey questionnaire responses are shown in Appendix 11. Appendix 12 gives the categories and coded frequencies associated with the responses.

Table 5.6 shows the number of responses received from members. A comprehensive representation across the globe included participants from Asia, Europe, the Americas and Africa. Of the 63 IRO members surveyed, the response rate received was 27, with no invalid responses. Thus, the adjusted survey response rate was calculated as follows: Adjusted Survey Response Rate: =  $(27/63) * 100\% = 42.6\%$ .

Table 5.6 shows the number of responses received from members. A comprehensive representation across the globe included participants from Asia, Europe, the Americas, and Africa.

**Table 5.5: Themes, categories and codes**

Themes	Categories	Codes
Organisational innovative capacity	Absorptive capacity	<ul style="list-style-type: none"> <li>• Business integration</li> <li>• Multidisciplinary</li> <li>• Technology diffusion</li> </ul>
Business leadership practice	Critical elements of a TRM framework	<ul style="list-style-type: none"> <li>• Benefit realisation</li> <li>• Customer understanding</li> <li>• Disciplined planning</li> <li>• Organisational support</li> <li>• Technology resilience</li> <li>• Systems thinking</li> <li>• Technology application</li> <li>• World view</li> </ul>
Organisational behaviour	Organisational process obstacles	<ul style="list-style-type: none"> <li>• Focus on revenue only</li> <li>• Lack of a robust risk analysis</li> <li>• Lack of disciplined execution</li> <li>• Lack of organisational support</li> <li>• Lacking ecosystem understanding</li> <li>• Operational perspective</li> <li>• Political interference</li> <li>• Shareholder first</li> <li>• Short-term strategic focus</li> <li>• Sponsor influence</li> <li>• Poor MRE</li> </ul>
Systems thinking prerequisites	Critical constructs	<ul style="list-style-type: none"> <li>• Agility</li> <li>• Climate change</li> <li>• Organisational resilience</li> <li>• Ecosystem understanding</li> <li>• Environmental appreciation</li> <li>• Political astuteness</li> <li>• Social conscious</li> <li>• Systems thinking (holism)</li> </ul>

**Table 5.6: Number of responses by country and region**

Zone	Country and Region	Number of responses
Asia	Japan	14
	China	2
	Hong Kong SAR	1
	Taiwan	1
	Philippines	1
Europe	Germany	2
	France	1
	Czech Republic	1
	Norway	1
America	United States	2
Africa	South Africa	1
Total:		27

5.4.4.1 Category: Absorptive capacity

This category addressed the insights of the IRO members of an organisation’s ability to recognise the value of new technological evidence, assimilate it, and apply it for commercial and social gain. The questions posed in the survey focused on current and emerging technology trends that would or could have a significant impact on the

ability of utilities to recognise the future value and thus remain relevant. Figure 5.28 shows the coded frequency for the word count category 'absorptive capacity' in green.

The comments and responses received indicated that an organisation's ability to recognise future technology value showed a changing trend of thinking compared with the previous focus group interactions. This was noted under this category that the code, 'technology diffusion', which is the process by which organisations adopt new technology widely, was by far the most significant. The feedback to the following question highlighted this view:

*What are the effects of COVID-19 on the energy system?*

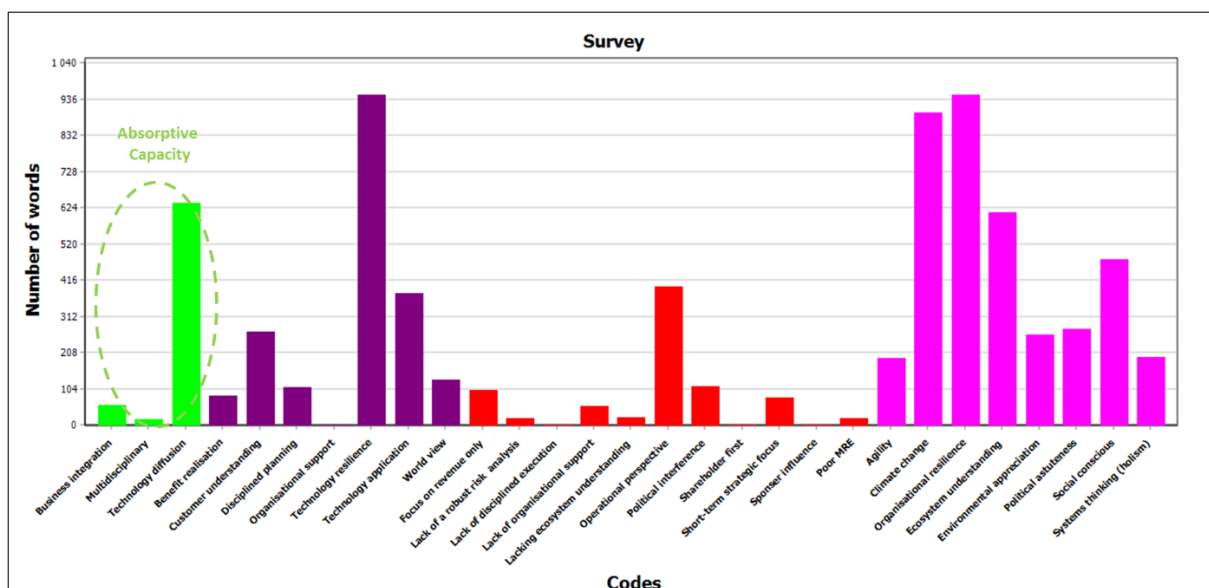
*Code 3) Technology diffusion: Accelerated digitisation - The digitalisation push could increase the pressure on traditional electricity providers to increasingly digitise the retail business. COVID-19 might speed up the digitalisation of processes and communication between people. Technologies such as digital twins and documentation and asset management might become more important.*

*Code 3) Technology diffusion: The basic measure is to reduce contact between people, and it is thought that remote work and remote inspection by robotics will be promoted. It has a high affinity with DX conversion, and it is necessary to develop data analysis technology collected by sensing and optimisation of communication/transmission means. For this reason, there is a need for technology that digitises information that comes out of electric power equipment in every part.*

*Code 3) Technology diffusion: As a countermeasure against the infection of the new coronavirus (COVID-19), we are taking measures such as telework and video conference ahead of urgent business trips. We believe that telework will further expand in the future as one of the measures for the new work style, not limited to measures against the new coronavirus (COVID-19) infection.*

Code 3) Technology diffusion: *The shift to a lifestyle that utilises the Web will accelerate even further, and it will be enhanced by remote communication and virtual reality. It is necessary to expand the hardware and software aspects that support them.*

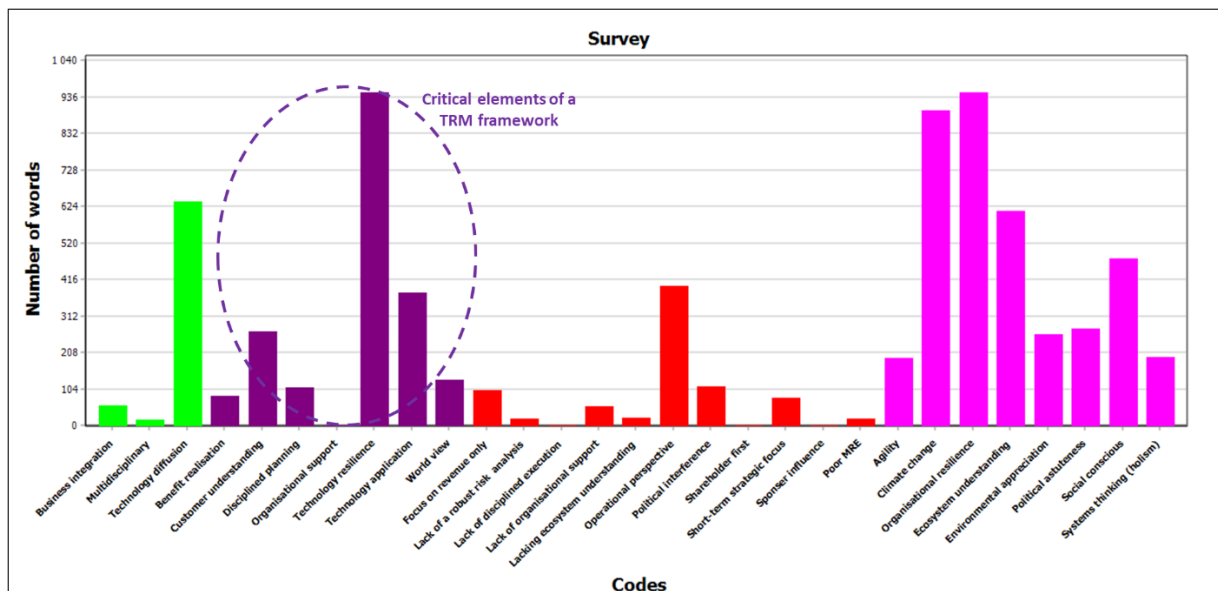
The comments and responses to the question undoubtedly highlighted the pandemic's importance and the critical need for organisations to take up digital technology. The comments *'new work style... the shift to a lifestyle that utilises the Web... reduce contact between people... remote inspection by robotics will be promoted'* clearly emphasise the immediate need to manage the pandemic through technology diffusion in all aspects of the business.



**Figure 5.28: The frequency of coded words for the category ‘absorptive capacity’**

#### 5.4.4.2 Category: Critical elements of a TRM framework.

This category reviewed the members' perceptions on effective business leadership practices from a technological application's viewpoint. The questions posed in the survey were associated with the critical strategic issues that influence an organisation's approach to technology selection. Figure 5.29 shows the coded frequency for the word count of the category 'critical elements of a TRM framework'. The codes are shown in purple.



**Figure 5.29: The frequency of coded words for the category 'critical elements of a TRM framework'**

In the analysis of this category, 'technology resilience' was by far the most dominant code, followed by 'technology application', 'customer understanding' and 'world view'. This is highlighted in response to the following question:

*What are the effects of COVID-19 on the energy system?*

Code 5) Technology resilience: *In order to avert the spread of infection, it may not be possible to maintain a system for sufficient maintenance and inspection of electric power equipment at the site. If the operator is infected, it may be*

*difficult to continue the operation. COVID-19 might speed up the digitalisation of processes and communication between people. We believe that telework will further expand in the future as one of the measures for 'new work style', not limited to measures against the new coronavirus (COVID-19) infection.*

*Based on national guidelines, we are implementing measures such as establishing a system that enables business continuity, even if employees are absent due to infection.*

Code 6) Technology application and Code 7) World view: *COVID-19 will accelerate the evolution of the global energy pattern. Electricity demand may decline for at least a year. On the other hand, in the medium- to long term, demand is expected to increase due to the acceleration of digitalisation and the domestic relocation of companies from overseas.*

Code 2) Customer understanding: *There is also a movement in society to change the lifestyle itself on the premise of 'with corona', and the structure of society and economy, the values and behaviours of customers are changing, and new needs are being met. Residential customers have seen a spike in electricity usage and consumption due to 'work from home' and online education during the lockdown imposition and quarantine measures. This trend is expected to gain traction post-pandemic and will promote consumer policies and programmes for the end-users.*

Following on from the above, the survey then asked the following question:

*What is the policy for coping with social demands in the field of power generation?*

This generated a number of responses from the members as shown in the following:

Code 5) Technology resilience and Code 6): Technology application: *'Increased risk awareness/security needed there could be a change in the application of existing technologies to reduce risks and an increase of demand*

*for security technologies and frugal, crisis-proof technologies (usable with local resources and under difficult conditions). The business disruption caused by the pandemic has created several cybersecurity risks that need to be addressed by the utilities.*

*Code 5) Technology resilience and Code 2) Customer understanding: We should promote distributed intelligent micro-grid applications. COVID-19 shows the lack of national capacity for energy emergency reserves and cross-regional power dispatch. It is necessary to strengthen energy emergency reserves and construct a multi-level and multi-energy reserve system through countries, regions and enterprises, to effectively suppress the fluctuation of electricity market in emergencies. Security of supply both to industrial and private consumers should be considered and not be put at risk at any time during this transition period.*

*Code 6) Technology application: Conventional power plants will still play an important role in near future since they will be mitigating threats regarding power generation intermittency. Until the energy storage will be commercially developed and able to cover seasonal energy demands, conventional power plants including Combined Cycle Generation Technology (CCGT) technology will remain a useful tool in how to stabilise generation from renewable sources.*

The following question related to strategic management was also asked:

*What is the policy for coping with social demands in the field of Strategic Management?*

The following is a sample of the comments given:

*Code 6) Technology application: We will actively incorporate new technologies such as AI and IoT to reduce costs, improve productivity, and create new services in the electric power business. The challenge is to secure and develop*

*human resources to promote digitalisation, as we have started the above-mentioned efforts late.*

Code 2) Customer understanding: *Increasingly, customers want more control over their energy consumption to maximise efficiency and minimise costs. Energy Management Solutions (EMS) is one of the opportunities that has arisen from such demand. It allows customers and facility managers to visualise the status of energy use, and offer greater control over how energy is stored, distributed, and used.*

It became apparent from the responses received under this category that the codes 'technology resilience', 'technology application', 'customer understanding' and 'world view' were the most significant components when considering current and future technologies under the present pandemic. It can also be seen from Figure 5.29 that technology resilience is more than double that of the next reported code, 'technology application'. It became clear from the responses under this category that 'technology resilience and application' were the most critical drivers under pandemic conditions and policies that would impact the approach to strategic management and thinking on future technologies.

#### 5.4.4.3 Category: Organisational process obstacles

This category addressed the views of members' regarding what they believed were the vital organisational shortcomings when considering the appropriateness of technologies. The questions posed in the survey focused on current and future technological trends that would have a substantial bearing on the ability of utilities to identify future value. Figure 5.30 shows the coded frequency for the word count for the category 'organisational process obstacles', which is shown in red.

The responses received from the survey revealed that there was still a focus on operational perspectives. However, there was a significant downward trend when compared to the Brussels and Berlin figures. It must be noted that during the pandemic phase, operational perspective can be seen as a short-term positive intervention. This

was followed by concerns around political interference and revenue streams, which showed an increase in concern compared to the previous two workshops. The following responses highlight this view:

Code 1) Focus on revenue only and Code 6) Operational perspective: *Although there are higher generation in renewables because of better resources, wind farms were affected by increased grid curtailments as a result of COVID-19. On-grid generation from one of Nuclear Power Stations was below expectations partly due to lower demand due to COVID-19 response measures. Reduced electricity demand as a result of the COVID-19 outbreak exerted pressure on the profit margins of our coal-fired generation portfolio... our performance was affected by lower demand, partly resulting from lockdown measures.*

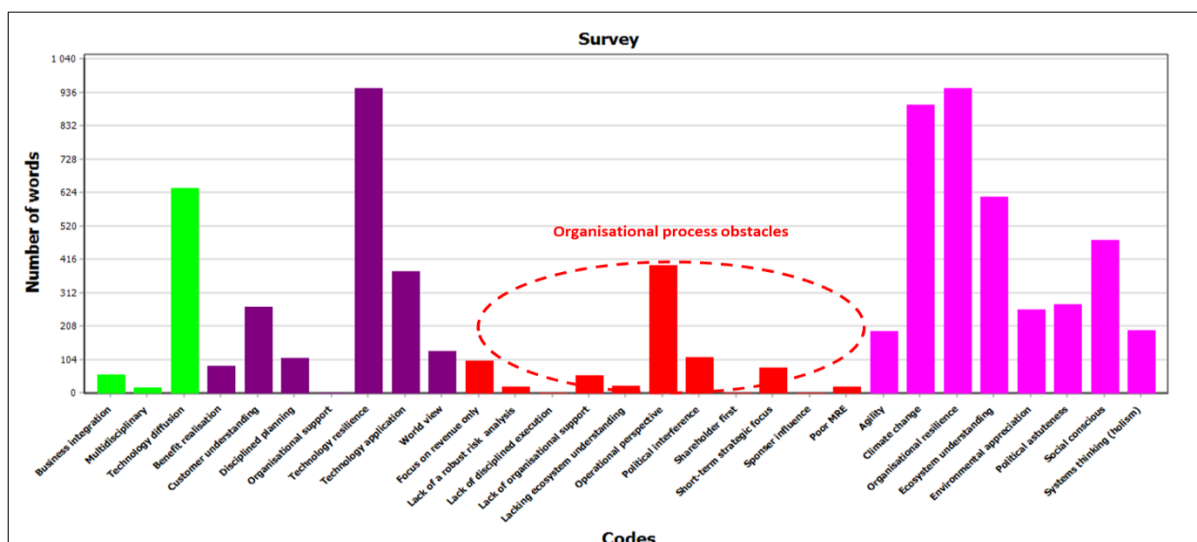
Code 7) Political interference: *Stronger influence of the state. Shifting the focus from the markets (failing in the crisis) to state could complicate international projects and make it necessary to build bilateral relations leading to direct or indirect state control of areas considered essential or in distress within the energy system. This point is uncertain though. The method varies greatly from country to country, and it is too irresponsible to impose what one country is doing, as another country cannot do the same thing.*

Code 9) Short-term strategic focus: *There is a risk that R&D and technological development will be reduced as a result of Covid 19. Probably public budgets for R&D and innovation will be less affected than the corporate ones since lots of companies will try to focus on recovering from the crisis, rather than maintaining or increasing their R&D and innovation budgets.*

Code 6) Operational perspective: *Our organisation is committed to ongoing innovation and enhancements to further strengthen its operational resilience at a time of uncertainty over the long-term impact of the global pandemic. During the pandemic it is more than ever obvious that grid robustness and stability is a key aspect to tackle and overcome the crisis.*

It became clear from the participating members' responses that an increase in operational perspectives was both a concern and a necessity during the pandemic. This was a result of the changing behaviours in working conditions for both utility staff and customers. However, what was evident was the increasing concern of state intervention and political meddling in electricity organisations and the increasing role of international political pressure on the utility business.

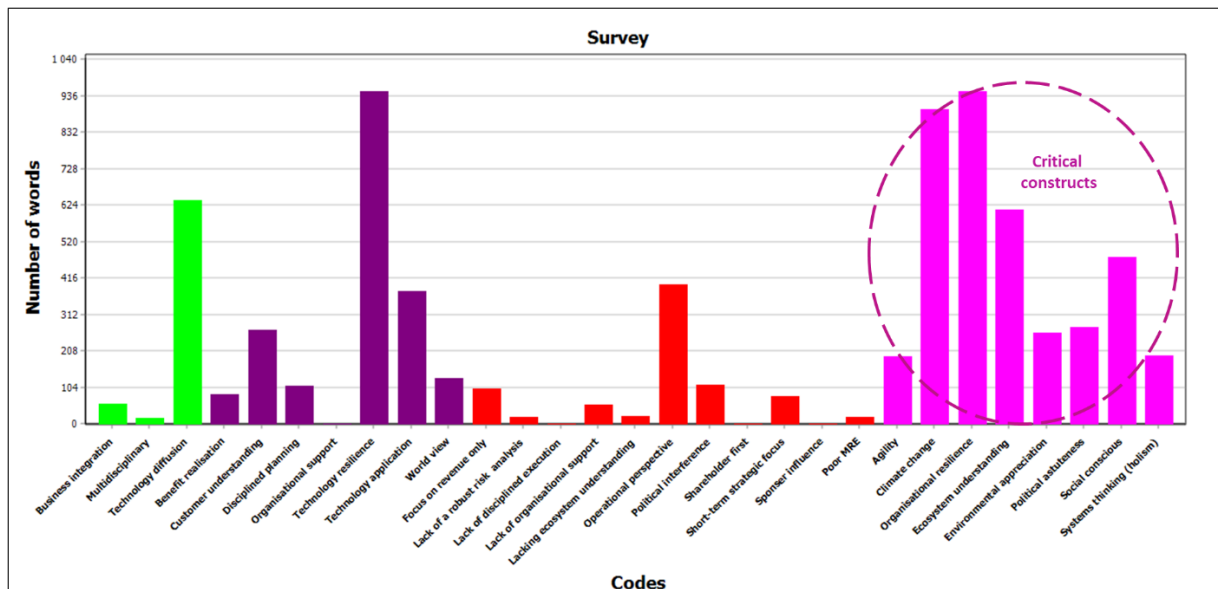
A further observation noted was that organisations were a lot more short-term focused during the COVID pandemic. Thus, the comments on the risk of reduced funding to research and development were noted as a concern.



**Figure 5.30: The frequency of coded words for the category ‘organisational process obstacles’**

#### 5.4.5 Critical constructs

This category addressed the perceptions and responses on the crucial elements in understanding the technology selection and that it can fully embrace systems thinking in the TRM process. Questions posed to the participating members considered the critical constructs essential for successfully applying a TRM process. Figure 5.31 shows the coded frequency (in light purple) for the category ‘critical constructs.’



**Figure 5.31: The frequency of coded words for the category ‘critical constructs’**

What was clear from the member's responses was that the impact of Covid had a considerable influence on how the organisation went about its approach to strategic thinking. When undertaking the thematic analysis of this category, it became apparent that ‘organisational resilience’ was considered the most important, followed by ‘climate change’, ‘ understanding’, ‘social conscious’ and ‘political astuteness’, which were deemed critical codes for consideration. The following comments show this:

Code 2) Climate change, Code 3) Organisational resilience, Code 5), Environmental astuteness and Code 8) Political astuteness: *One of the most important impacts of COVID-19 is the influence of clean energy transition. Due to COVID-19, planned investments might decrease and the transition to clean energy technologies might slow down. If fossil fuel costs remain low, it can also be more difficult for clean energy technologies to succeed. On the other hand, the supportive investments planned by the European Commission are large, and have the potential to boost clean energy technologies after COVID-19.*

Code 4) Understanding and Code 6) Social Conscious: *Moreover, with respect to the ‘new normal’ and the societal shifts to ‘work home’ an online education,*

*a certainty in the near-term is an emphasis on sustaining and improving our existing service reliability, as well as focusing on electrification to provide those in remote and far-flung areas with access to power, which is vital to function in this new environment. Increased working from home and other factors are increasing the role of the community in energy management as well as many other functions – resiliency, reliability, electrification, decarbonisation.*

*Code 8) Political astuteness: The state-mandated retreat into the domestic environment and the disillusionment caused by the failure of international supply chains could lead to a regionalisation of the economy and a stronger self-sufficiency for emotional reasons (neighbourhood) as well as rational motives (security of supply) and a stronger self-sufficiency.*

*Code 2) Climate change and Code 3) Organisational resilience: COVID-19 also promotes the transformation of social production and lifestyle, and gives rise to the digital transformation of energy industry. For example, it will contribute to the development of energy block-chain technology and unattended digital energy enterprises. It is a good opportunity to transform the energy structure amid major changes in working styles and values. Shoulder our share of the responsibility to mitigate climate change, and manage the key risks posed to our business by transforming away from carbon-emitting generation.*

*Code 3) Organisational resilience and Code 7) Systems thinking (holism): Given the potential for policy changes, our targets are not static. While our 2020 decarbonisation target aligns with the 2°C scenario, our remaining targets for 2030 and beyond do not. We intend to strengthen these targets at least every five years, responding to changes in climate science, technology, and energy policy in relevant territories. We expect the countries where we operate to strengthen their pledges under the Paris Agreement over time. We will continue to calibrate our pace of change with our key markets, and we will measure our progress.*

Code 3) Organisational resilience: *The development of renewable energy is important for decarbonisation, but since solar power and wind power generation are greatly affected by the weather, thermal power generation also plays a major role in the adjustment. In order to achieve both environment and economy, it is necessary to utilise the characteristics of each power source, such as renewable energy, nuclear power generation, and thermal power generation, and to have a well-balanced power source composition based on regional characteristics.*

Code 3) Organisational resilience: *Cyber security is not a separate issue that is the sole responsibility of a dedicated department but a business risk that needs to be managed holistically and integrated into daily operations. Resiliency is critical and becoming more critical.*

The 2020 survey generated several significant comments and information. From the analysis, it was noted that participating members had given comparable information and answers. The codes with the highest frequency were organisational resilience, technology resilience, climate change, technology diffusion understanding and social consciousness, which accounted for more than 60% of the codes analysed as shown in Figure 5.32. A significant finding from the survey was that participating members acknowledged that under the Covid conditions, the importance of understanding technology and organisational resilience was a critical and vital component for consideration in technology roadmapping initiatives.

The top five codes, 'organisational resilience', 'technology resilience', 'climate change', 'technology diffusion' and 'ecosystem understanding' account for over 55% of the coded frequency. What was noticeable was that the code 'operational perspective' was within the top ten codes with a frequency of 5.1%, indicating that operational focus from a technical perspective was necessary.

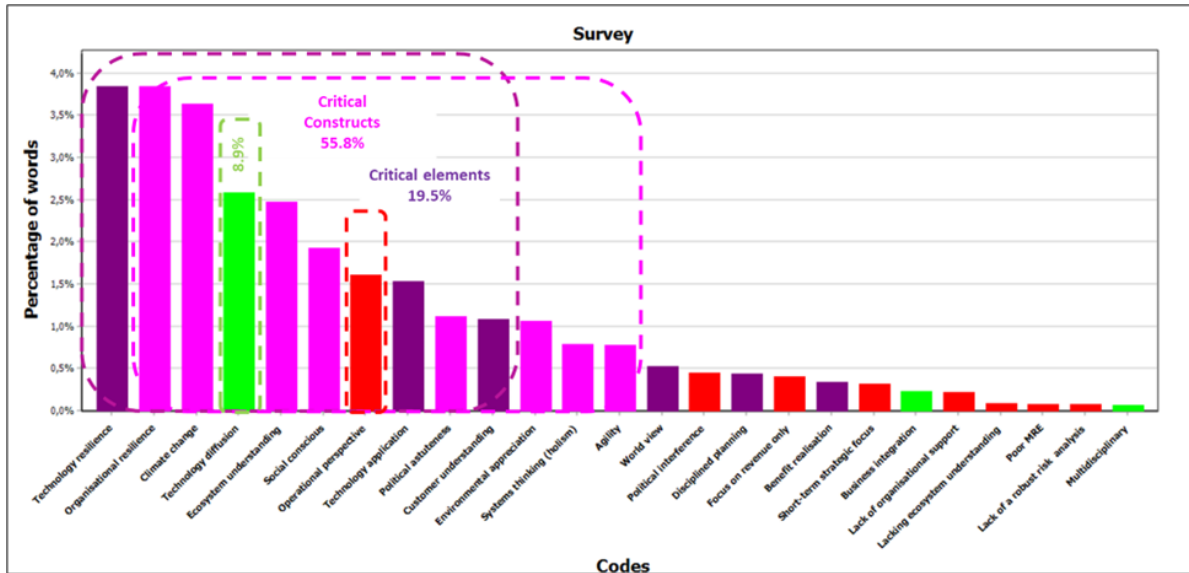


Figure 5.32: Frequency of codes for the survey dataset

## 5.5 Conclusion

The results from the phase of this study provided the researcher with a sample of two focus group workshops and a survey which examined specific categories and codes. This research phase's value lies in the thematic approach applied to the qualitative data. The in-depth analysis of the two focus group workshops and survey, the data gathering (i.e. the group discussions, observations, and questionnaires) allowed the researcher to study the key variables considered as critical for developing a conceptual technology roadmapping framework.

In addition, the sequence of the quantitative analysis and the two focus group workshops and surveys over the three years provided the researcher with comprehensive insights into the critical components considered prerequisites in developing a conceptual roadmapping framework.

The results from the Brussels workshop showed that the critical issues raised by the group were that codes linked to the 'category organisational process obstacles' were of significant concern. The codes with the highest frequency were 'operational perspective', 'organisation silo mentality', 'short-term strategic focus,' 'corporate politics', and 'sponsor influence'. The group considered these as critical impediments

to the TRM process.

A further finding was that the codes 'organisational ignorance' and the 'lack of an appropriate return on investment' were seen as problematic under the same category. It was evident from the discussions that the participants strongly believed that current thinking within global utilities was highly short-sighted and operationally focused. The results highlighted that very little consideration was given to systemic thinking, customer understanding, and the political environment. In addition, the Brussels focus group workshop and the quantitative survey results generally indicated a convergence of results.

The second focus group workshop occurred some 18 months after the first workshop, resulting in a highly thought-provoking process of thinking and exchanging ideas and discussions. The Berlin workshop results differed significantly from the Brussels workshop. Nevertheless, a clear trend was noted from the first workshop's short-term operational thinking viewpoint to a more holistic view in the second.

The participants in the Berlin workshop acknowledged that it was imperative that organisations had to understand and comprehend the technological relationships and interrelationships of their businesses on the ecosystem. Following this approach would undoubtedly enhance a more robust delivery of a technology roadmap that would be meaningful for an organisation's sustainability. In addition, the results highlighted that only a deep understanding of environmental concerns including climate change; political awareness and customer understanding were critical elements of consideration in developing technology futures.

The comparative analysis results for the Brussels and Berlin datasets highlights the divergent thinking between the two focus groups. Where the Brussels results showed a predominantly operational perspective, the Berlin group indicated a shift to more of an external environmental standpoint. The researcher suggests that this change in the thinking from the Berlin dataset could be in response to the increased global demands of carbon emission reduction from electricity utilities, and the fact it was one of the key outcomes from the COP.

An important conclusion from the survey analysis revealed a changing trend in thinking towards technology and organisational resilience, ecosystem understanding and climate change as these were crucial inputs into the technology roadmapping process. It is suggested that this substantial reactive change in thinking was in response to the COVID-19 global pandemic. The participants acknowledged overwhelmingly that under COVID-19 conditions, the importance of technology resilience in achieving organisational resilience was a critical driver for short-term technology changes and long-term technological planning.

The results from this analysis have meaningfully contributed to a better understanding of the critical issue in answering the research questions of this thesis. In addition, it resulted in the researcher gaining a richer awareness of key concepts that were significant considerations in developing a conceptual roadmapping framework.

## CHAPTER 6

### RESEARCH RESULTS AND FINDINGS

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#### 6.1 Introduction

This chapter analyses and integrates the qualitative data from the two focus group workshops (Brussels and Berlin) and the survey questionnaire. Firstly, the analysis examines the specific categories and related codes. Secondly, the analysis examines the integrated view of the combined qualitative study from the three datasets from both a category and code perspective. Finally, the analysis of the results and findings will be described in terms of the relationships and associations linked to this study's research questions.

The qualitative phase of the study sought to address four research questions. The first question is related to critically evaluating the current roadmapping methodologies to determine the links between utility technology and absorptive capacity. The second research question looked at the critical elements and drivers for a more systemic/holistic framework in terms of an improved framework that is more responsive and robust to an electricity utility's needs in the context of future technological adaptations.

The third research question evaluated the shortcomings and limitations of the current technology roadmapping process regarding business processes and procedures. The fourth research question sought to define the critical constructs of a conceptual framework for technology roadmapping responsive to an electricity utility changing environment.

#### 6.2 Integration of qualitative datasets

Figure 6.1 shows the code frequency in descending order for the Brussels, Berlin and survey datasets over three years. A clear trend is seen where the Brussels focus group

indicated that the key shortcomings in developing the technology roadmapping process were a predominance of short-term operational issues and an internal perspective, resulting in a lack of long-term technology foresight.

Eighteen months on, the Berlin focus group revealed a vastly different perspective from the Brussels findings. The findings indicated a move to a more outward ecosystem perspective than that projected by the Brussels dataset. Key drivers described by this group as vital for consideration in developing technology roadmaps were environmental impact, climate change and the political environment.

The survey results show evidence of a substantial departure in thinking compared with the previous two focus group results. What was evident from the survey 2020 analysis was that the majority of members agreed that under the COVID-19 conditions, the understanding of resilience, both organisational and technological, was imperative for designing technology futures and the life-cycle approach in the development of a conceptual technology roadmapping framework.

Figure 6.2 shows the word cloud and the tree-map and indicates the shifting trend in responses over the three years. The tree-map indicates a strong trend from mainly an operationally focussed organisational to a more outwardly thinking ecosystem perspective and resilience understanding in the approach to technology roadmapping.

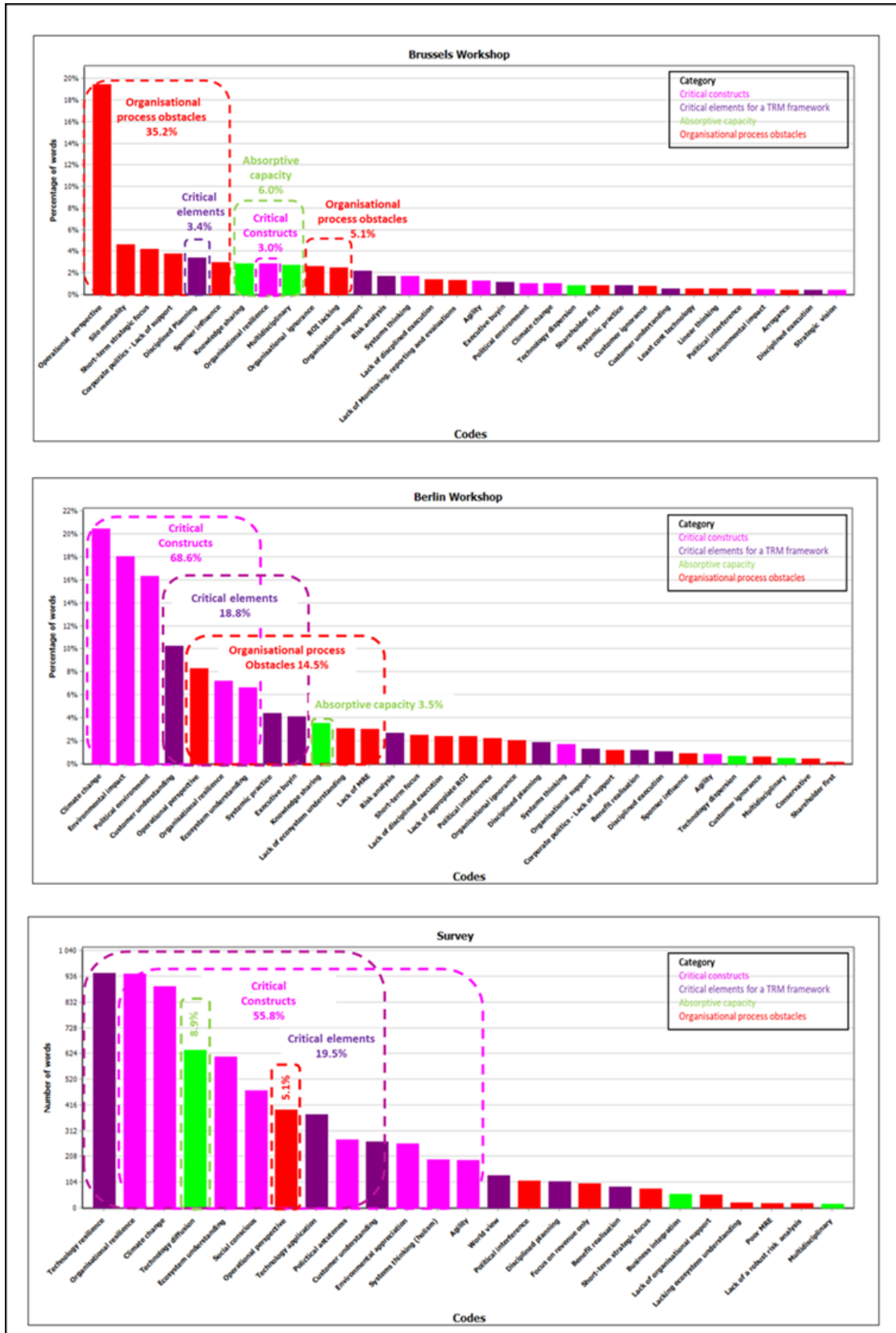
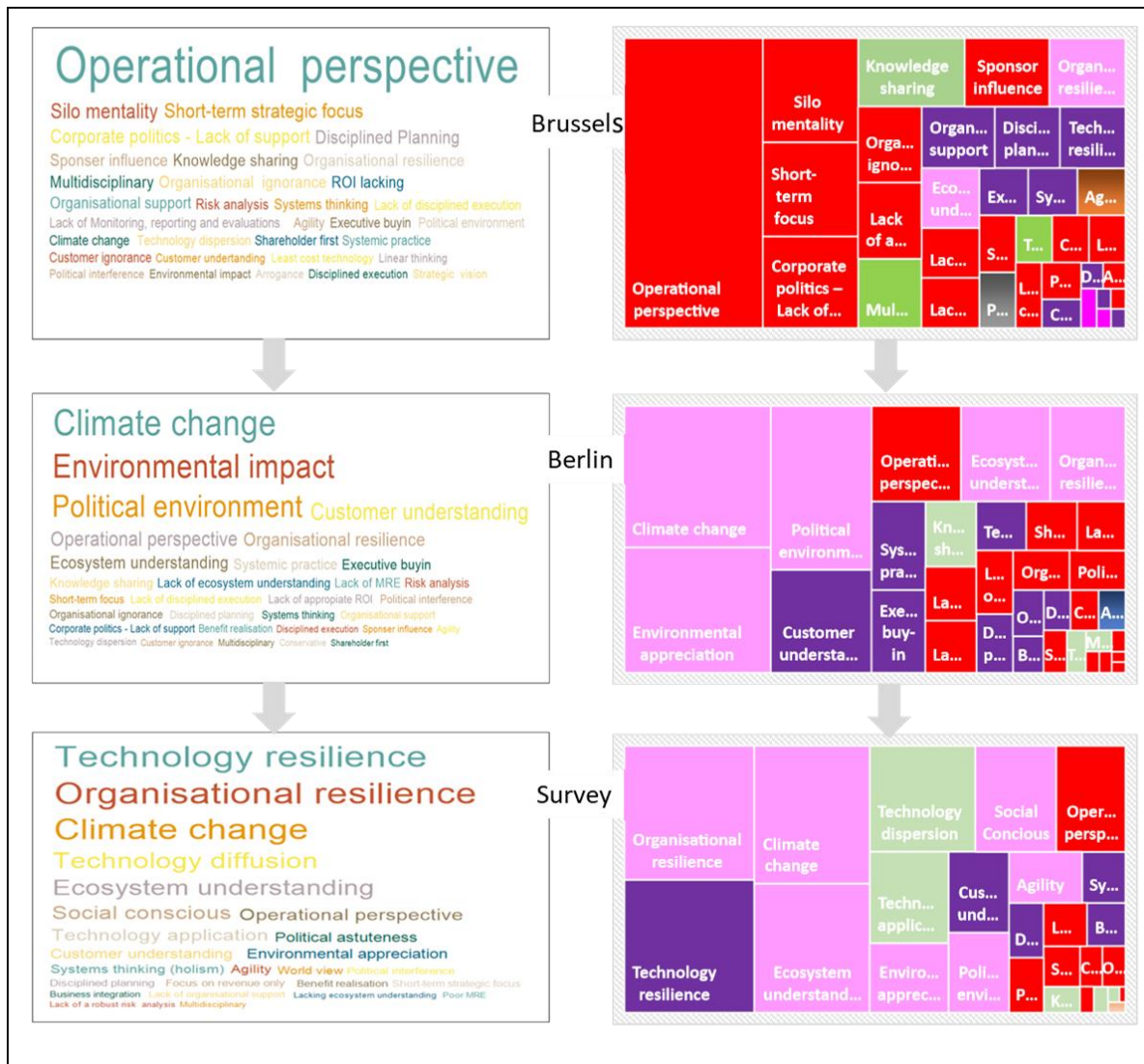


Figure 6.1 Frequency of codes for Brussels, Berlin, and survey datasets



**Figure 6.2: Word cloud and tree map of codes for the Brussels, Berlin and survey datasets**

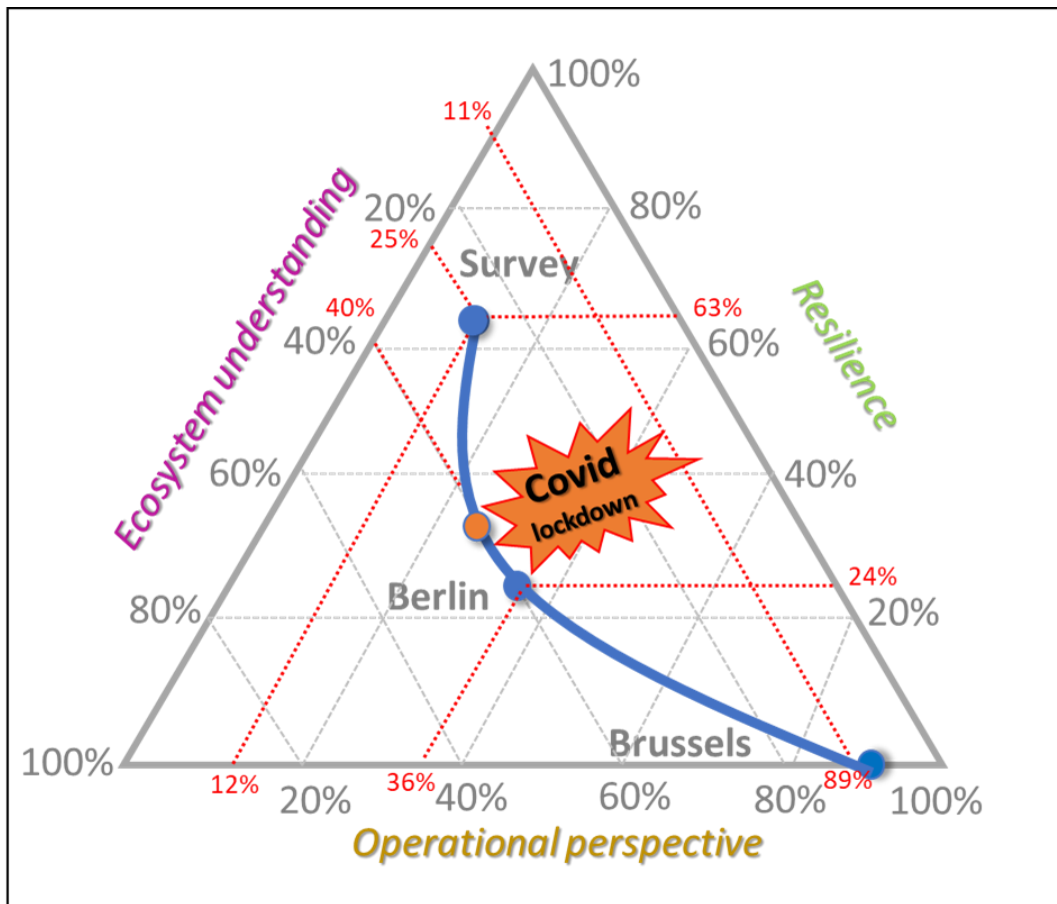
Figure 6.3 displays a trajectory analysis for the codes, ecosystem understanding, resilience and operational perspective from the three datasets over time. The figure shows a gradually increasing gradient between the Brussels and Berlin data points.

The Brussels results indicate that the code ‘operational perspective’ was the most dominant (89%), followed by ‘ecosystem understanding’ at 11%. On the contrary, the Berlin workshop results indicated a significant decline in the code ‘operational perspective’ (36%), an associated increase in ‘ecosystem understanding’ (40%), and ‘resilience’ at 24%.

This trajectory change confirmed a moving away from a predominantly internal focus to a more external and ecosystem focus. The researcher suggests this could result from the increasing global climate change demands and the intense concerns regarding long-term environmental impacts (KPMG, 2019:16). A further motivation for this view is that the Conference of Parties (COP) meetings were held between the two focus group workshops were highly critical of electricity utilities' carbon emissions and the need for them to start actioning urgently in applying appropriate technologies in the transition to a future greener economy (KPMG, 2019:16).

The data from the Berlin workshop and the survey results show an exponential and dramatic increase in the data trajectory, potentially indicating an abnormal event that resulted in a radical change in mindset which impacted the survey dataset. Furthermore, as discussed in Chapter 5, the emergence of the Covid-19 pandemic and the rapid global lockdown in early 2020 changed how the world responded to technology.

According to Twilio (2021:7) in their survey of companies, 97% reported that Covid-19 had sped up their digital transformation. In the context of their digital strategy, the Covid-19 pandemic accelerated it by six years on average (Twilio, 2021:7). An article by McKinsey (2021) reported that 'the US e-commerce penetration experienced ten years' worth of growth in just three months'. There is widespread agreement that this cataclysmic event of Covid-19 had an extraordinary impact on organisational thinking and technology resilience. As can be seen from the trajectory analysis (Figure 6.3), the survey dataset shows an overriding tendency of resilience as an obligatory consideration in all future technology roadmapping initiatives.



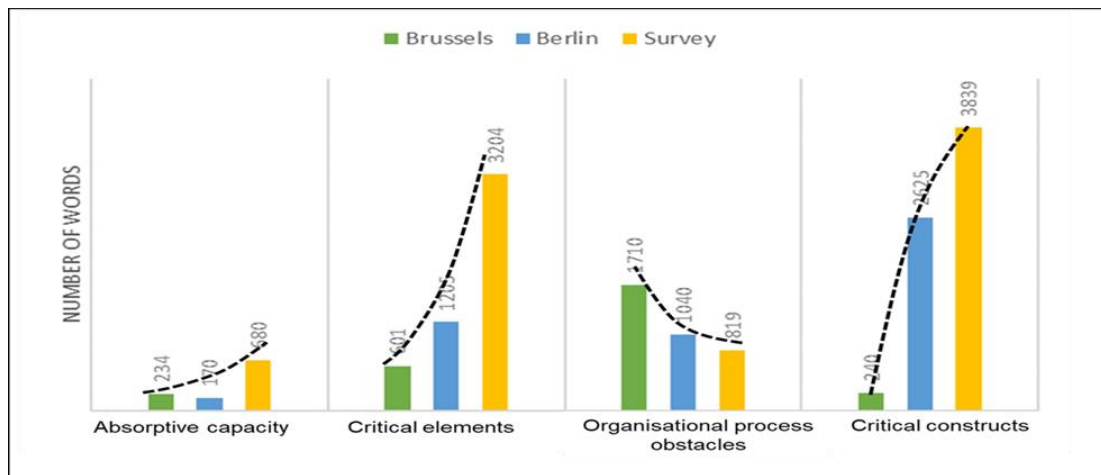
**Figure 6.3: Trajectory analysis for codes ecosystem understanding, operational perspective and resilience**

Figure 6.4 shows the integrated cumulative frequency and the trends for the codes associated with the categories ‘absorptive capacity’, ‘critical elements’, ‘organisational process obstacles’, and ‘critical constructs’ for the three datasets. The figure shows that the categories ‘absorptive capacity’, ‘critical elements’ and ‘critical constructs’ reveal an exponentially increasing trend over the three years, indicating an ongoing concern that current roadmapping practises are not meeting current organisational requirements.

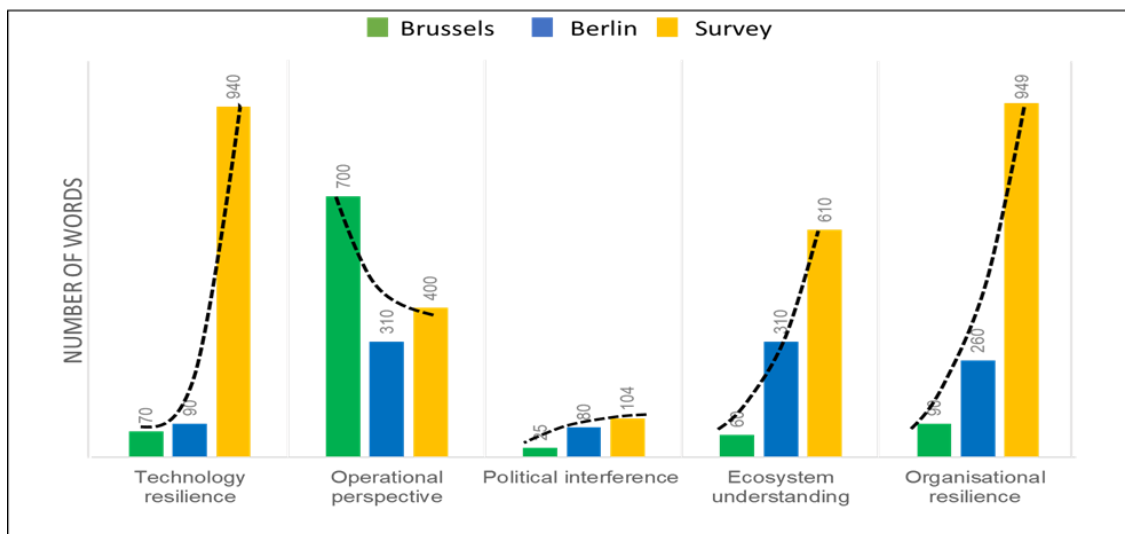
The category ‘organisational process obstacles’ showed a downward trend, suggesting a gradual move from a predominantly internal focus to a more outward systemic perspective in terms of the approach adopted to technology roadmapping development. An important finding from the analysis was that the IRO members acknowledged overwhelmingly that the Covid-19 pandemic had resulted in a dramatic

change in mindset and their approach to technology application and long-term planning.

Figure 6.5, which illustrates selected codes from the various categories, shows the exponential increase in technology and organisational resilience, ecosystem understanding and the increasing influence of political interference on technology planning. This resulted in a more outward perspective of the ecosystem and is confirmed by the declining trend in the code 'operational perspective'.



**Figure 6.4: The cumulative frequency of all codes for all categories for the Brussels, Berlin and survey datasets**



**Figure 6.5: The frequency of selected codes from the three datasets**

### 6.2.1 Absorptive capacity

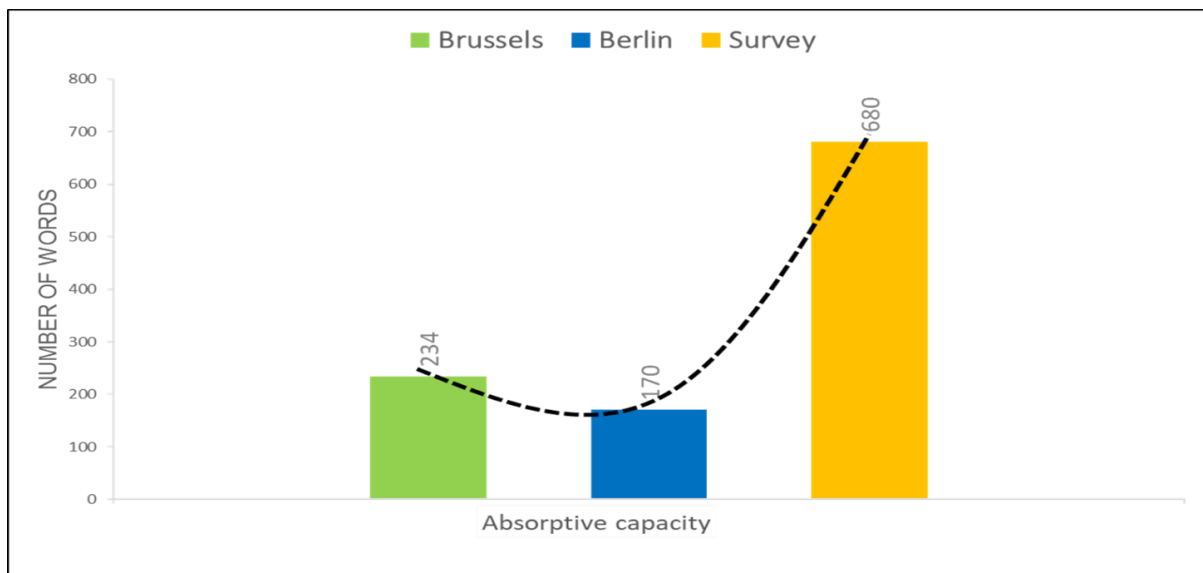
A prerequisite for organisations to remain competitive and sustainable is continuously exploring and transforming into new areas of market development and technological capabilities. According to Christensen and Raynor (2003:327) an organisation's capacity to flourish with any noteworthy transformation depends on three capabilities; resources, processes, and values. Resources can include tangible and intangible assets, including facilities, technology solutions, and intellectual property. Processes are those activities that organisations perform to transform resources into finished products for the end-user, and values embrace the ethical principles and ideologies that an organisation lives by.

The role of technology roadmapping within an organisation plays a significant role in this transformation process and the ability for organisations to remain competitive. According to Naqshbandi and Kamel (2017:20) absorptive capacity can be defined as 'an organisation's ability to identify, assimilate, transform, and use external knowledge, research and practice'. Thus, absorptive capacity is the rate at which an organisation can absorb and use scientific, technological, or other knowledge inside or outside the organisation for commercial gain. Simply put, it measures an organisation's ability to learn to remain competitive and sustainable. Therefore, the first research question (RQ1) posed is critical in understanding how the technology roadmap influences the ability of electric utilities ability to absorb and apply current and future technologies.

#### ***RQ1: How do the current roadmapping methodologies link with electricity utility technology and absorptive capacity?***

Figure 6.6 shows the total cumulative coded frequency for absorptive capacity from the three datasets (Brussels, Berlin, and the survey). The figure indicates an increasing trend in word count frequency from the Brussels meeting to the final qualitative survey. This increasing trend is evidence that organisations need to improve their approach to absorbing and assimilating scientific and technological knowledge within the technology roadmapping outputs.

This upward trend suggests a significant shift in thinking from an organisational absorptive capacity perspective over the three years. The technology roadmapping process significantly influences an organisation's ability to absorb new knowledge. It highlights the increasing importance for organisations to appreciate and acknowledge the value of the technology roadmapping process and what they have to offer the organisation regarding technology awareness, technology intelligence, and impending technology strategies, and thus overall organisational competitiveness.



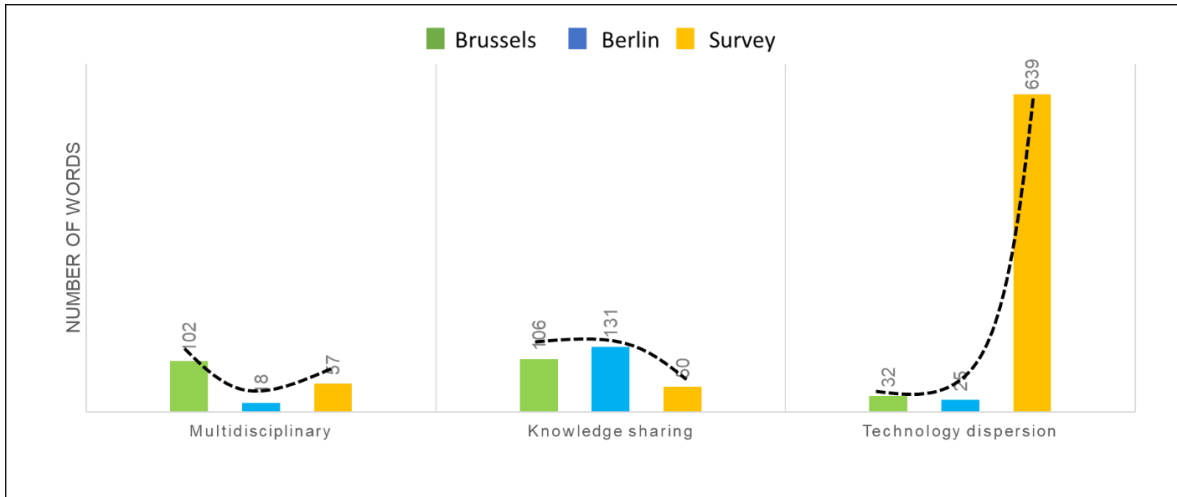
**Figure 6.6: The total frequency of codes for the category absorptive capacity for the Brussels, Berlin and survey datasets**

Figure 6.7 shows the code frequency and trends embedded in the category 'absorptive capacity' collected over the study period. The multidisciplinary code indicates a slightly declining trend, indicating a relatively consistent participant view. In addition, the code 'knowledge sharing' trend is declining; however, the evidence of the declining trend in the codes 'multidisciplinary' and 'knowledge sharing' suggests that the IRO members' opinions on how their organisations approach and value the current technology roadmapping methodology are perceived as generally satisfactory.

The code 'technology dispersion' indicates a fascinating trend; for the first two focus group meetings, 'technology dispersion' was not a critical factor in the members' views. However, in the survey feedback, the dataset analysis revealed an exponential increase in the code frequency. This exponential increase highlighted the importance the IRO members placed on technology dispersion within their organisation.

A significant result from the survey analysis was that members acknowledged overwhelmingly that under the COVID-19 conditions, technology dispersion was a critical factor and an essential driver of organisational survival and the ability to remain relevant. It is proposed that this sudden increase in the code 'technology dispersion' was in reaction to the COVID-19 pandemic, where technology resilience, application and dispersion became critical and significant factors for organisational design and survival.

The findings of research question one indicated that the current technology roadmapping methodology and approach do not adequately meet all the requirements that enable organisations to absorb and apply technological knowledge for ongoing competitiveness. However, the findings did highlight that when a crisis arises, e.g. COVID-19, organisational behaviour and culture change significantly to a reactive mode, resulting in the rapid implementation of technology (application and dispersion), which becomes imperative for the organisation's survival. Therefore, the application and use of technology roadmaps for guidance during this period were substantial in the technology diffusion and dispersion process.



**Figure 6.7: The frequency of codes for the category absorptive capacity**

### 6.2.2 Critical elements

The category ‘critical elements’ considered the key organisational leadership attributes of practices, processes, and policies that can fully contextualise and apply the concept of systems thinking in all aspects of decision-making in the technology roadmapping process. This category aimed at understanding what organisational systems and processes enable higher technological performance for growth and sustainability. This is particularly relevant in today’s complex, dynamic and volatile environment.

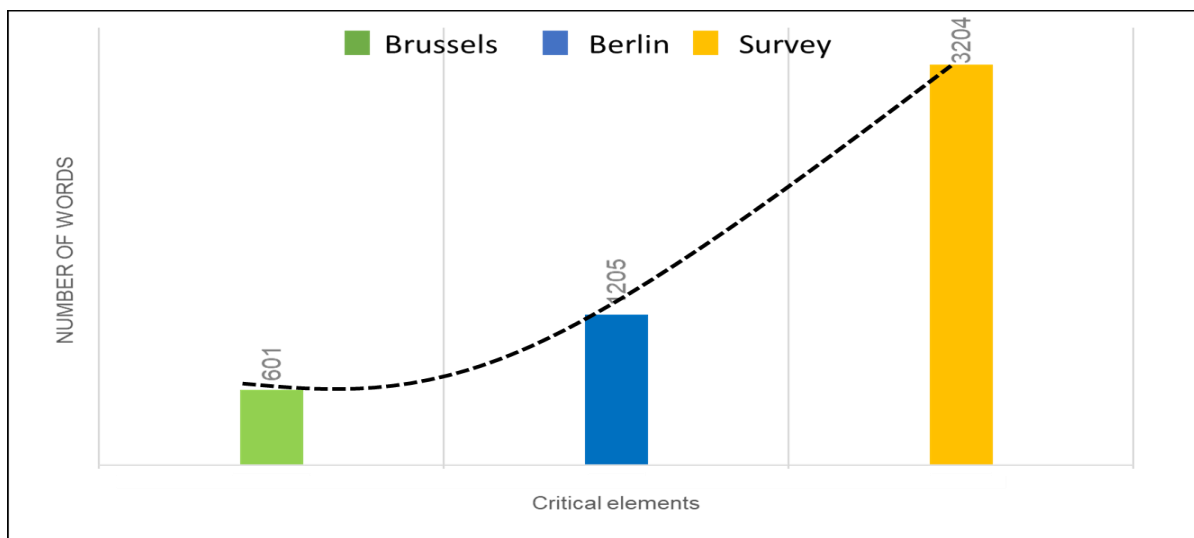
The second research question (RQ2) is significant in understanding the critical elements for successfully implementing a holistic technology roadmapping framework. In addition, what are the key drivers that assist and influence the development of an improved framework? The following states the second research question:

***RQ2: What are the critical elements and drivers for a more systemic/holistic framework?***

Figure 6.8 indicates the total coded cumulative frequency for the category ‘critical elements’ from the three data sets. The figure shows an increasing frequency trend from the first focus group workshop of over 600 to the last survey result of over 3200. This generally high number of coded frequencies in all three datasets highlights the significance of the participating members and the importance of the critical elements

and drivers that need to be embedded within an organisational culture for an enhanced and robust technology roadmapping framework.

The substantial increase in the trend suggests that organisations are becoming much more aware of the critical elements' importance in the successful design and process of formulating the roadmapping framework. From the results of the analysis, it is evident that the focus groups perceive this category, 'critical elements', as imperative for a more enhanced roadmapping framework.



**Figure 6.8: The total frequency of codes for the category 'critical elements' for the Brussels, Berlin, and survey datasets**

Figure 6.9 shows the code frequency and trends embedded in the category 'critical elements' obtained over the study period. Except for the code 'organisational support', the remainder of the codes showed increased trends over the three years.

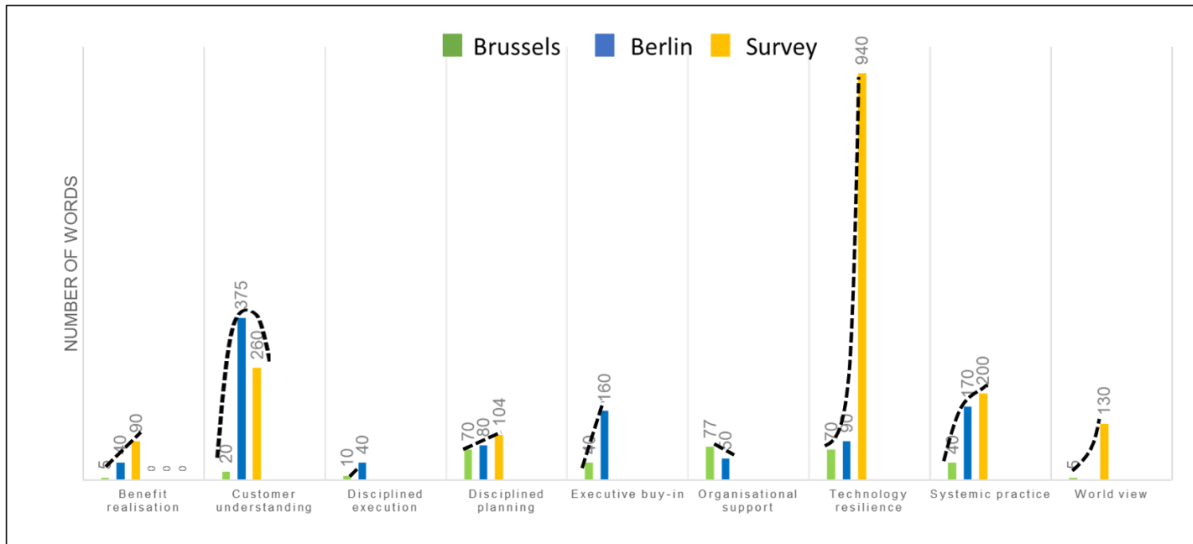
The findings indicate that from the members' perspectives, the most significant area of concern in this category deals with the inability of the existing technology roadmapping framework to integrate technological risk in a time of crisis and the ability of the framework to incorporate a long-term technology resilience development plan.

The figure shows an exponential increase in code frequency of 'technology resilience', from a word count of 70 at the Brussels focus group meeting to a frequency of over 900 from the survey results. This increase highlighted the concern expressed by the

focus group members.

The next crucial driver in this category was 'customer understanding' and the incapability of the current roadmapping to consider, embrace, and adopt an approach where the customer is central in the developmental process of the roadmapping framework. The figure shows a noteworthy increase in the trend of the coded frequency from the first focus group meeting of 20 to the second meeting of 375. Interestingly, there was a decline (yet still significant) in the frequency count of 260. Thus, a key finding related to the research question is that 'customer understanding' is a key driver and a central component in the developmental process of the technology roadmapping framework.

The codes of 'systemic practice' and 'worldview' were the following two areas that were deemed problematic from the qualitative study in terms of the current approach to technology roadmapping. The figure shows that the code frequency of 'systemic practice' had an increasing trend throughout the three datasets. The results confirm that the systemic understanding and practice approach to the current roadmapping framework was lacking. It highlighted the need to include and integrate a systemic and holistic understanding of the dynamic, changing, and complex environment in future technology roadmapping practices.



**Figure 6.9: The frequency of codes for category ‘critical elements’ for the Brussels, Berlin, and survey questionnaire datasets**

### 6.2.3 Business process obstacles

The category ‘business process obstacles’ considered those critical process obstructions that hinder and constrain the development of current technology roadmapping frameworks. This category aimed to identify those organisational obstructions and process limitations, both internally and externally, that play a significant part in influencing the existing approach of the roadmapping framework and process.

As described in the literature chapter, current roadmapping methodologies and processes are constrained by several limitations both within organisations and externally. A significant contributor to the shortcomings in the roadmapping framework is the impact that organisational processes inflict negatively on the roadmapping process.

As defined by Wang and Sun (2010:211),

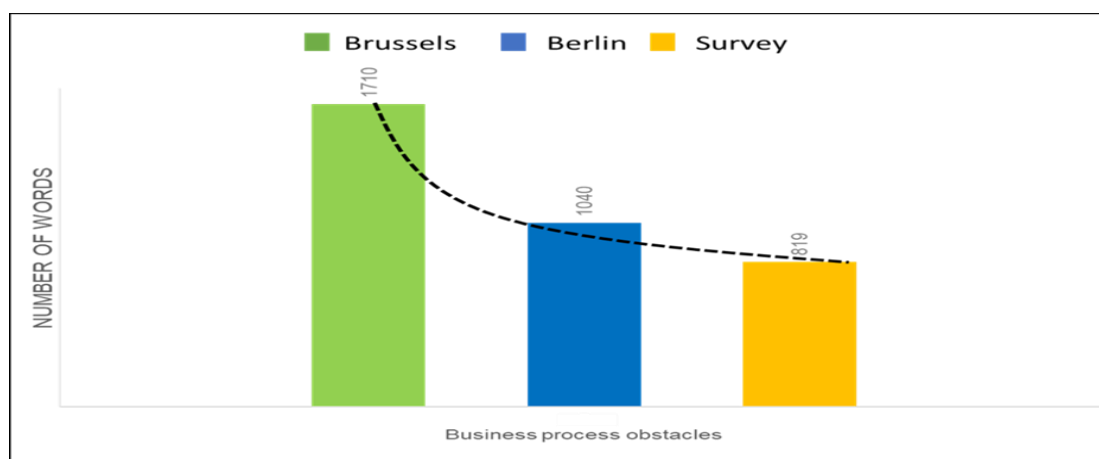
*Activities that establish the business goals of the organisation and develop process, product and resource assets which when used will help to achieve business goals (Wang and Sun, 2010:211).*

Thus, business processes describe how work gets done in an organisation irrespective of type or size. Unfortunately, approximately 75% of all business problems are embedded within defective business processes (Vom Brocke and Rosemann, 2015).

The third research question (RQ3) is related to the current obstacles existing within and external to organisations that negatively influence the existing roadmapping process and framework. Understanding the constraints and shortcomings would allow the researcher to define and refine improved processes in developing a proposed conceptual technology roadmapping framework. The third research question was as follows:

***RQ3: What are the shortcomings and limitations of the current technology roadmapping framework?***

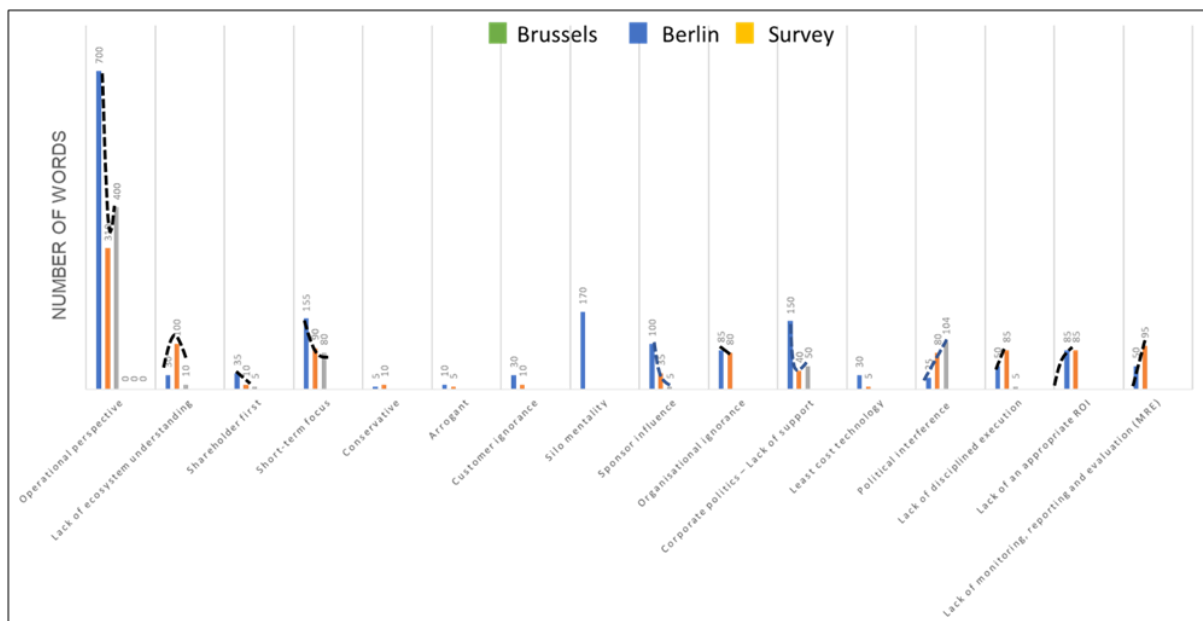
Figure 6.10 shows the total coded cumulative frequency for the category ‘business process obstacles’ from the three datasets. The figure indicates a declining trend in word count frequency from 1700 to under half of that in the survey study results. However, the results still show a relatively high frequency count in this category, indicating that the participants still consider current business process obstacles as significant components that could negatively influence current roadmapping practices and processes.



**Figure 6.10: The total frequency of codes for the category ‘business process obstacles’ for the Brussels, Berlin and survey datasets**

Figure 6.11 illustrates the specific code frequency and trends embedded in the category ‘business process obstacles’ for the three datasets. The figure shows that the code ‘operational perspective’ shows the most significant frequency of 700 at the Brussels focus group workshop, indicating a prevalence that the technology roadmap approach was mainly concerned with short-term technology solutions and lacked a detailed analysis of the longer-term strategic technology requirements.

The frequency trend showed a decrease for the second meeting and an increase for the final dataset. It is important to note that operational asset management is an essential requirement for electricity organisations and that the respondents expected that more emphasis should be placed on future technologies that would assist organisational and technological sustainability and competitiveness.



**Figure 6.11: The frequency of codes for the category business process obstacles for the Brussels, Berlin, and survey datasets**

The researcher's private communication with a senior executive from one of the largest global electric utilities confirms the above findings. The following comment was made related to the utility's research and development budget allocation concerning operational management perspectives:

*Hi there Greg,*

*We are well, thank you! We are however in a 4<sup>th</sup> Covid wave and so work is again to homework for about 4 days per week and travel is no longer allowed between.....*

*Hope in S. Africa all is going well although you are entering summer so that usually helps a lot?*

*I don't have what you ask for ..... but the reason that we don't have this at ..... our R&D budget is for 75 % not managed at corporate level R&D, but at Business Unit (BU) level for only operational issues. We at the R&D Division corp level we manage only around 25% of the funds whilst the other funds 75% (150 million USD) is spent by our BU's. AND most of that money is spent on legacy operational issues.*

The code 'sponsor's influence' was an essential factor and limitation in the roadmapping process. However, the figure shows a gradual decline in concern over the three years. This suggests that the impact over the three years regarding the sponsor's influence on the roadmapping process had declined to the point that it was not of significant concern.

However, what was clear from the results was the increase in political interference in the roadmapping process, which is seen as a critical factor in the subsequent success of the roadmapping framework and final outputs. It is proposed that the increase in this code frequency and lack of disciplined execution could be a consequence of the increased political effect on the overall technology roadmapping process. It highlights a key and critical limitation in the roadmapping process, potentially impacting the execution phase.

The codes 'lack of appropriate return on Investment (ROI)' and 'lack of monitoring, reporting, and evaluation' indicate an increasing trend in frequency over the three years. This indicates that the current roadmapping framework is limited in how the roadmapping process is monitored, evaluated, and reported during its lifecycle and what value the final framework brings to the organisation in terms of ROI.

#### 6.2.4 Critical constructs

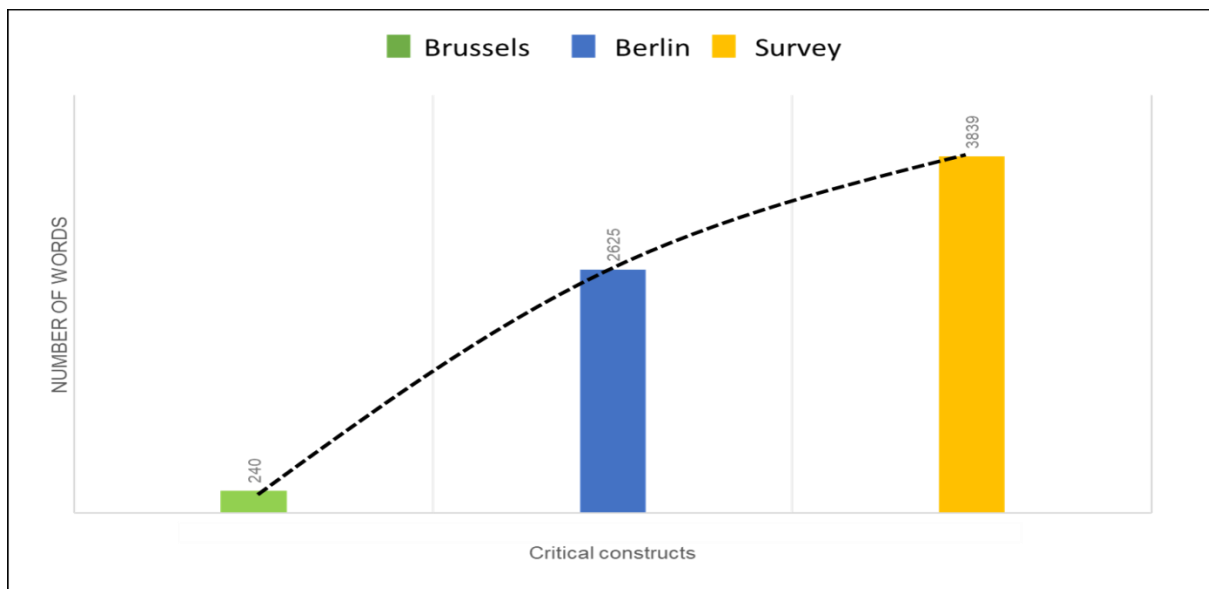
The category 'critical constructs' aimed to search for alternative and enhanced behaviours in thinking which could be adapted and applied to develop a conceptual technology roadmap. It is further proposed that these critical constructs could be integrated into and form the essential building blocks of the conceptual technology roadmapping framework.

The fourth research question (RQ4) posed enquiries about the fundamental foundations required in the roadmapping framework that would enhance the ability and agility of an organisation in responding to a rapidly changing technological environment.

The following was the fourth research question:

***RQ4: What are the critical constructs of a conceptual technology roadmap that is capable of responding to an electricity utility environment?***

Figure 6.12 shows the total coded cumulative frequency for the category 'critical constructs'. Again, the figure shows an increasing trend in frequency throughout the three years. The increasing trend in frequency for the category 'critical constructs' suggests that the current thinking and approaches in the design and application of technology roadmaps are inadequate. It is also assumed from the data that a fundamental shift in design, thinking, and effort is required for a new approach to technology roadmapping



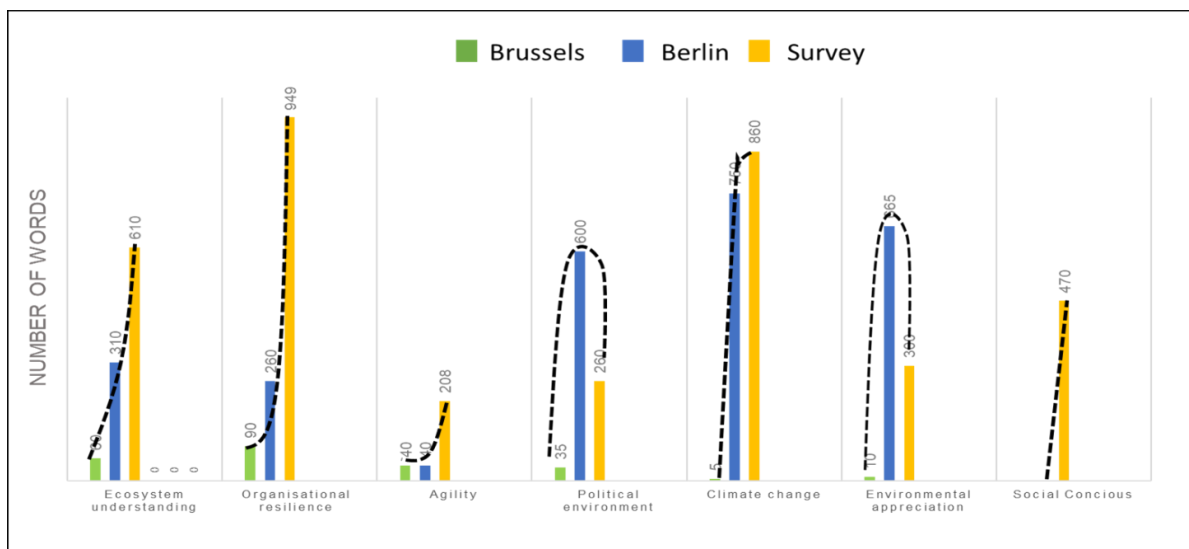
**Figure 6.12: The total frequency of codes for the category ‘critical constructs’ for the Brussels, Berlin, and survey datasets**

Figure 6.13 illustrates the code’s frequency and trends embedded in the category ‘critical constructs’. In reviewing the figure, it is noted that all the codes have dramatically increasing trends from all the datasets, except for the codes ‘political environment’ and ‘environmental appreciation’, where exponential increases in trend frequencies are observed for both the Brussels and Berlin datasets.

Notably, for both the codes ‘political environment’ and ‘environmental appreciation’, there was an almost identical decrease in frequency for the survey dataset. It is suggested that during the last survey of the study, and the fact that the global COVID-19 pandemic dominated the health and geo-political discussions worldwide, the constant political pressures that had been placed on electric utilities subsided to a certain degree and the feedback from the survey shows evidence of this.

From the findings of this category, the fundamental building blocks for a solid foundation for an alternative technology roadmap must be built on the understanding and application of organisational resilience, ecosystem understanding, and environmental appreciation, including social consciousness and climate change. These are the fundamental building blocks for developing a conceptual technology roadmapping framework. These building blocks will allow utilities to become more

agile, adaptive, and responsive to the dynamic and ever-changing technological future required for organisational sustainability.



**Figure 6.13: The frequency of codes for the category ‘critical constructs’ for Brussels, Berlin, and survey datasets**

### 6.3 Conclusion

The findings from the qualitative phase of this study provided the researcher with a sample of two focus group workshops and a survey which examined specific categories and codes. This research phase's value lies in the thematic approach applied to the qualitative data. By an in-depth analysis of the two focus group workshops and survey, the data gathering (i.e. the group discussions, observations, and questionnaires) allowed the researcher to study the key variables critical for developing a conceptual technology roadmapping framework. In addition, the sequence of the two focus group workshops and surveys over the three years provided the researcher with comprehensive insights into the critical components considered prerequisites in developing a roadmapping framework.

In reviewing the qualitative analysis of the three datasets, a significant trend emerged. The findings indicated a movement away from an internal thinking (operational and short-term) approach to a sudden reactionary change due to the unforeseen global onset of COVID-19, where organisational and technological resilience and eco-system

understanding took centre stage and dominated the drivers in the technology roadmapping approach.

The findings from the Brussels workshop showed that the critical issues raised by the group that codes linked to the category 'organisational process obstacles' were of significant concern. The codes with the highest frequency were 'operational perspective', 'organisation silo mentality', 'short-term strategic focus', 'corporate politics', and sponsor influence. The group considered these as critical impediments to the TRM process.

A further finding was that the codes of 'organisational ignorance' and the 'lack of an appropriate return on investment' were seen as problematic under the same category. It was evident from the discussions that the participants strongly believed that current thinking within global utilities was highly short-sighted and operationally focused. The results highlighted that very little consideration was given to systemic thinking, customer understanding, and the political environment.

The second focus group workshop occurred some 18 months after the first workshop, resulting in a highly thought-provoking process of thinking and exchanging ideas and discussions. The Berlin workshop results differed significantly compared to the Brussels workshop. Nevertheless, a clear trend was noted from the first workshop's short-term operational thinking viewpoint to a more holistic view in the second.

The participants in the Berlin workshop acknowledged that it was an imperative that organisations had to understand and comprehend the technological relationships and interrelationships of their business on the environment. Following this approach would undoubtedly enhance a more robust and resilient delivery of a technology roadmap that would be meaningful for an organisation's sustainability.

In addition, the group also highlighted the belief that only a deep understanding of organisational resilience and understanding (which can be seen as inclusive of climate change, social consciousness, and political awareness) was a fundamental requirement and consideration in the application and approach to technology roadmapping. The group also suggested that customer understanding was an additional imperative, followed by organisational knowledge sharing and the need for

executives to buy into the roadmapping process.

Thus, it is evident from the findings that the current TRM methodology and approach lack inclusivity at the organisational and ecosystem levels. At the organisational level, enhancing absorptive capacity is critical in driving people participation through ongoing engagement and alignment, thereby enhancing knowledge sharing and technology dispersion throughout the TRM process. At the ecosystem level, the reluctance to consider organisational resilience, ecosystem understanding and environmental appreciation are fundamental gaps in the roadmapping framework. A crucial weakness in the current roadmapping approach was the lack of a long-term technology resilience strategy.

A further shortcoming in the existing TRM was an organisational obsession with short-term technology and operational solutions; thus the need to ensure that a balanced approach for short and long-term technology solutions needs to be embedded in the TRM framework. An important finding was the impact of ongoing political interference and influence on the TRM process and subsequently impacting the final outputs of the TRM.

Lastly, there is a lack of ongoing monitoring, reporting, and evaluation in the roadmapping implementation plan. Figure 6.14 shows a high-level synopsis of the key findings regarding the essential success factors and barriers required to cogitate as key drivers in developing a robust conceptual technology roadmapping process.

	Success factors	Barriers to success	
	Technology resilience	Lack of business support	
	Ecosystem/systemic understanding	Focus only on short-term (operational)	
	Technology diffusion	Company culture/politics	
	Organisational resilience	Organisational ignorance	
	Commitment by all management	Lack of executive & senior commitment	
	Customer understanding	Lack of a robust methodology	
	Political astuteness	Lack of an effective MRE	
	Social conscious	Lack of disciplined planning	
	Benefit realisation	Silo mentality	
	Environmental appreciation	Lack of political astuteness	
High	Low	Low	High

**Figure 6.14: Critical success factors and barriers to success to consider in the technology roadmapping approach**

In conclusion, organisations today face many challenges in continuously being exposed to increasing levels of technology complexity in a rapidly changing business environment where they are bound to compete. At the interface between technology complexity and rapid change, volatility and instability are generated, producing bursts of environmental turbulence, making it extremely difficult for organisations to manage technology futures, due to an increasingly dynamic and complex change where system conditions become chaotic.

In addition, these complex interfaces can produce surges of innovation and obsolescence, which continually alter and transform the business environment in which they operate.

The findings presented in this section provide detailed insights into the perceptions, feelings, and views of the workshop participants and survey results, which reflect the varying and sometimes thought-provoking opinions in the approaches leading to the development of a conceptual technology roadmapping framework.

To quote Cleary and Malleret (2006:45),

*The companies who succeed in these tumultuous times are those that brace for the certainty of turbulence and rise to the challenge of skilfully managing the risks attendant on operating in unpredictable environments.*

## CHAPTER 7

### CONCLUSION

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*It seems that the faster we embrace new technologies, the less we are able to understand them. What is the long-term effect of this galloping technological revolution? In today's new world, it is nothing less than a matter of responsible citizenship to grasp the nature and implications of technology (Pearson and Young, 2002:53).*

#### 7.1 Introduction

The overall objective of this research study was to examine, explore, understand, and develop a conceptual technology roadmapping framework that is responsive to an environment where the rate of technological adaptations and changes outpace business processes. There are several methodological gaps and shortcomings in the current approach to technology roadmapping practices, and as Saritas (2013:117) proposes, a systemic approach needs to be considered in future analytical frameworks. Systemic practice is based on the premise that the world is interconnected and interrelated, and the fact that technology is advancing and converging at an exponential rate, thus understanding the ecosystem holistically is a business imperative.

This chapter reflects these considerations in that the thesis's critical lenses, research aims, and questions are central in considering the current methodological shortcomings and limitations with the aim of the development of a conceptual technology roadmapping framework. In addition, this chapter covers answering the ultimate aim and research questions, research limitations, and recommendations for future research. The theoretical, conceptual framework proposed in Chapter 3 laid the foundation and building blocks for answering the research questions.

## 7.2 Summary of findings

The analytical propositions were derived from a mixed method research design involving qualitative focus group workshops and quantitative surveys. Table 7.1 shows the propositions identified and developed to address the aim of the study and the four main research questions: i) How do the current roadmapping methodologies link with electricity utility technology and absorptive capacity? ii) What are the critical elements and drivers for a more systemic/holistic framework? iii) What are the shortcomings and limitations of the current technology roadmapping framework? iv) What are the critical constructs of a conceptual technology roadmap capable of responding to an electricity utility environment?

**Table 7.1: Summary of objectives, research questions and the key propositions**

<b>Aim: To develop a conceptual technology roadmapping framework that is responsive to an ecosystem where the rate of technological adaptations and changes outpace business processes.</b>		
<b>Objectives</b>	<b>Research questions</b>	<b>Determined propositions</b>
To critically evaluate current roadmapping methodologies in order to determine the links with utility technology and absorptive capacity.	1) How do the current roadmapping methodologies link with electricity utility technology and absorptive capacity?	<p>The current technology roadmapping process limits electricity utilities' capability to absorb and assimilate new technical knowledge and technology awareness.</p> <p>The main priority for technology roadmaps of organisations is to facilitate technology implementation and dispersion for market integration and organisational competitiveness.</p> <p>The technology roadmapping process can alter the current organisational behaviour and culture of a reactive mode to a pre-emptive mode.</p>

**Aim: To develop a conceptual technology roadmapping framework that is responsive to an ecosystem where the rate of technological adaptations and changes outpace business processes.**

Objectives	Research questions	Determined propositions
Determine the critical elements and drivers for a more systemic/holistic framework.	2) What are the critical elements and drivers for a more systemic/holistic framework?	<p>A priority for a technology roadmapping framework is to reflect technology risks by developing a comprehensive technology resilience strategy.</p> <p>The critical element indicates that technology roadmaps must integrate and apply systems thinking, systems practice and understanding into all elements of the design architecture and process.</p> <p>A significant driver for a more holistic roadmapping framework is the ability of the framework to embrace and adopt an approach where the customer is central to the developmental process.</p>
To determine the reasons and the extent of the shortcomings of the current technology roadmapping processes.	3) What are the shortcomings and limitations of the current technology roadmapping framework?	<p>The main obstacle entrenched in the current technology roadmapping framework is the inability to consider longer-term strategic technology options because it is predominantly a short-term and internally operational focus.</p> <p>The impact of external political interference plays a critical role in the eventual outcome of the technology roadmapping process.</p> <p>The current technology roadmapping framework lacks the ability to monitor, evaluate and report (MER) on technology implementation and execution, thus its inability to present a return on investment.</p>
To construct a conceptual	4) What are the critical constructs of a conceptual	The technology roadmap as an imperative encompasses organisational resilience and

<b>Aim: To develop a conceptual technology roadmapping framework that is responsive to an ecosystem where the rate of technological adaptations and changes outpace business processes.</b>		
<b>Objectives</b>	<b>Research questions</b>	<b>Determined propositions</b>
framework for technology roadmapping that is responsive to an electricity utility.	technology roadmap that is capable of responding to an electricity utility environment?	<p>ecosystem understanding as its fundamental building blocks in its underpinning and design.</p> <p>The conceptual technology roadmapping framework must apply the systemic practice in its approach to its design.</p> <p>Environmental drivers, including political awareness, social consciousness and climate change, must be considered as imperatives throughout the design process.</p> <p>A fundamental attribute of a conceptual roadmapping framework is that it must be responsive, adaptive, agile and flexible to the dynamic changing technological landscape, and thus, continuous monitoring and updating are critical prerequisites.</p>

The three propositions that addressed the first research question with the inferences that; i) the current technology roadmapping process limits electricity utilities' capability to absorb and assimilate new technical knowledge and technology awareness, and ii) the main priority for technology roadmaps of organisations is to facilitate technology implementation and dispersion for market integration and organisational competitiveness, and the proposition that iii) the technology roadmapping process can alter the current organisational behaviour and culture of a reactive mode to a pre-emptive mode. As is the case for all the research questions, it is essential to note that the following propositions are only the critical issues extracted and discussed, and several relevant issues and findings are discussed in chapters 5 and 6.

The propositions that responded to the second research question highlighted critical aspects of essential elements required for a holistic roadmapping framework. The propositions indicated that the inclusion and adoption of a technology resilience

approach integrated with systemic practice are critical elements for implementing a holistic roadmapping framework.

Research question three dealt with the shortcomings and limitations of the current technology roadmapping framework. The propositions discussed highlighted that the significant obstacle inherent in the existing technology roadmapping framework was the inability of the roadmap to be more technology strategic focussed due to an obsession with operational issues.

In addition, a key finding was that the current roadmapping lacks the ability to monitor, evaluate, and report the benefits realisation of the executable outputs.

Research question four was concerned with the critical constructs of a conceptual technology roadmap that creates value in terms of organisational responsiveness. Four propositions addressed the research question with the inferences; i) that the technology roadmap must incorporate organisational resilience as its fundamental building blocks in its underpinning and design, ii) that the conceptual technology roadmapping framework must apply systemic practice in its approach to its design and integrating understanding, iii) that environmental drivers, including political awareness, social consciousness and climate change, must be considered imperatives throughout the design process, and iv) that the framework must be responsive, adaptive, and agile to the dynamic changing technological landscape.

### **7.3 Proposed conceptual technology roadmapping framework**

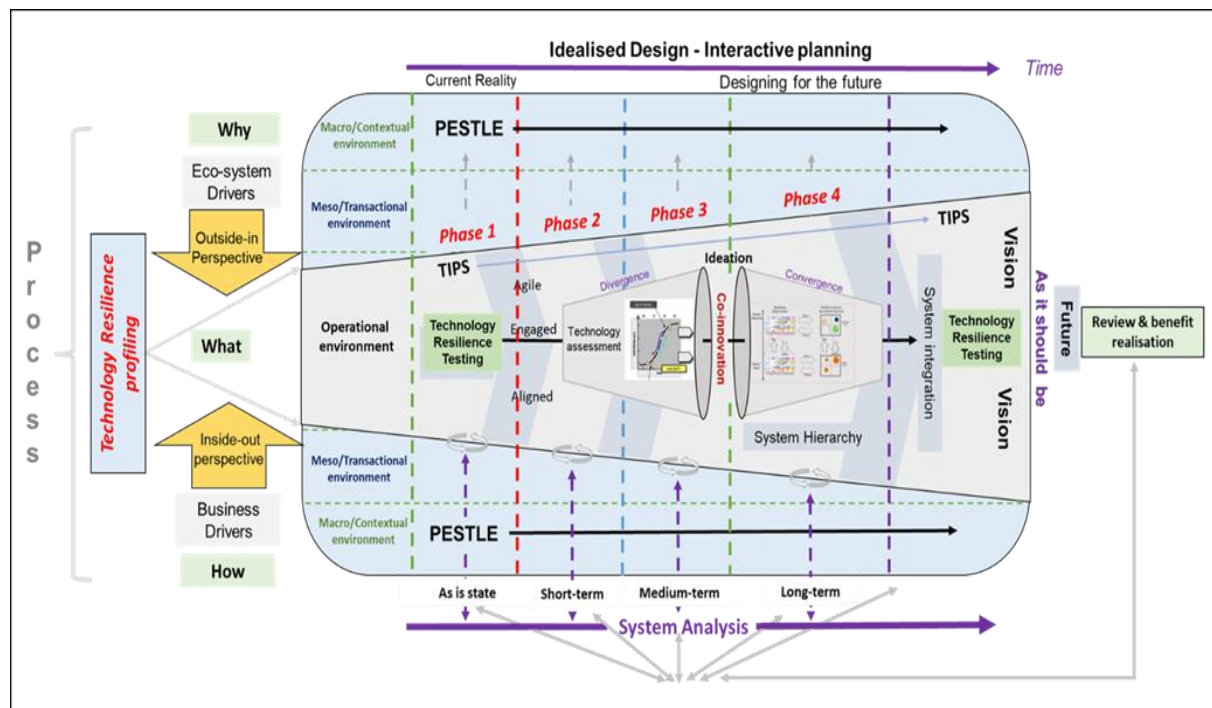
As described in Chapter 3, the conceptual technology roadmapping framework proposed for this study has been derived from the mixed method research design of this study and the seminal work on systems theory and idealised design of Ackoff (1970, 1978, 1999).

In addition, the TIPS core framework described by the Da Vinci Business School (2022:15), the work of Phaal *et al.* (2013:17) and Kerr and Phaal (2022:15) for introducing the notion of a multi-layered TRM framework structure, and the TMT theory as described by Loorbach and van der Lindt (2007:21) in their analysis of complex

technology systems were crucial contributing factors in the development of the conceptual framework.

Figure 7.1 presents the proposed conceptual technology roadmapping framework indicating the various components and techniques that could be applied in the technology roadmapping process. The framework for electricity utilities addresses the roadmapping process in a multi-dimensional visualisation format. The rationale for the proposed framework is that the components articulated in the conceptual framework follow a systems perspective and have a technology resilience and testing approach as its foundation throughout the process.

In addition, the findings of this study have strongly suggested that technology resilience, organisational resilience, and ecosystem understanding are regarded as the most critical drivers in the technology roadmapping developmental process. Therefore, the work of Xiao and Cao (2017:22) on their proposed theoretical model for organisational resilience and Tosen's (2022:19) work on the technology resilience capsule were considered essential in developing the conceptual technology roadmapping framework.



**Figure 7.1: Proposed conceptual roadmapping framework**

The following details a step-by-step approach to the conceptual roadmapping framework process which is based on findings from the data analysis.

### 7.3.1 Preliminary phase

This phase of the process aims at understanding the organisation in terms of defining the scope of the study, the needs and requirements of the existing strategy, setting the boundary conditions, identification of key role players, and the business and ecosystem driver landscape.

For the roadmapping process to be meaningful, acceptable, and adopted by the organisation, it requires a multi-stakeholder representation. This necessitates the involvement of technology providers (the organisation), the adopters and key stakeholders. The literature has shown that in current roadmapping models, stakeholders have a passive and minor role in the process, and at best only the dominant ones are considered (Kamtsiou *et al.*, 2014:25), resulting in the stakeholder's requirements often being ignored. This leads to the roadmap becoming an academic exercise with no organisational or stakeholder buy-in (Strauss and Radnor, 2004; Kerr and Phaal, 2022:15).

Adopting a multi-stakeholder representation throughout the process captures propositions 1 to 3 and 6, allowing the active involvement of the organisation's players and stakeholders to be fully immersed in the process. Allowing the organisation to be part of the technology planning process leads to an enhanced awareness of the long-term consequences of technology implementation and absorption. The following principles are proposed for this phase:

#### 7.3.1.1 Set boundary conditions

Ensure that there is consensus on the approach and process to be applied in the transition from current reality to the as it should state. The scope and timeline of the roadmap should be defined in terms of short and medium-term and with a more strategic view of the long-term vision (proposition 7).

The roadmap's boundary, scope, and drivers should be clearly articulated in that risk and resilience are seen as core drivers of organisational sustainability. Thus, organisational and technology resilience are regarded as imperatives in understanding current and future ecosystem and business drivers within the technology landscape (propositions 4, 5 and 10).

#### 7.3.1.2 Provide organisational leadership

An effective technology roadmapping steering committee which comprises organisational executives, experts, and stakeholders, which includes users and customers (proposition 3). The 'participative principle' entails that all stakeholders should preferably contribute and participate in the numerous phases of the planning process. The continuity principle states that planning is a perpetual process, since the needs and desires of the organisation's stakeholders will vary over time.

Proposition 8 suggests that there is political interference in the eventual outcome of the roadmapping process, and thus the consideration of including appropriate government personnel in the committees could well enhance the roadmapping process. The organisational leadership must ensure its strategic vision and objectives are embedded into the roadmapping design.

#### *7.3.2 Phase 1 - Current reality systems perspective*

In this phase, the current reality systems analysis is undertaken. The participants will deliberate and analyse the organisation's current state of affairs from an inside-out and outside-in ecosystem perspective, which entails a thorough multi-directional system analysis of the operational, transactional and contextual environments.

This approach allows the participants to co-innovate and co-create on critical technological positions related to current technology threats, weaknesses, obstructions and opportunities. This is a crucial phase of the initial roadmapping analysis, as without fully understanding the existing technological weaknesses,

obstructions and shortcomings, it is practically impossible to plan effectively for the future.

This phase also ensures that the engagement among the participants is aligned with a shared intent and understanding of the current state of affairs and the organisation's future vision. Throughout the process, the participants must continuously reflect, review, and deliberate on the preliminary activities outputs and adapt and realign. The following approach is proposed for this phase:

#### 7.3.2.1 Develop system requirements

Transition theory is the understanding of the behaviour and dynamics of complex systems and subsystems continuously interacting and adapting. The basic concept of transition management relies on the approach that the world is interconnected and that organisations need to view the world from a systemic perspective due to continuous changes in the socio-technical and technological systems (proposition 5).

The holistic principle focuses on the planning process at the system analysis level and the need to understand the interactions and connectivity at the various levels of the environment. Systems move from established paradigms to new ones, and organisational planning must consider the ongoing changing technological and social upheavals.

Once the system analysis and requirements have been identified, the idealised design process begins, and the roadmap's foundation is developed regarding the end-state vision. The rationale for the framework is that the components articulated in the roadmapping framework follow a systems perspective and technology resilience testing as its foundation.

#### 7.3.2.2 Analytical approach

The roadmapping framework is dynamic as it includes the time component, which is considered a critical factor in organisational competitiveness and sustainability. It

poses three critical questions which need to be explored and established; Where are we now? Where do we want to go? How can we get there? These are at the very heart of organisational planning.

### 7.3.3 Phase 2 - Short-term systems perspective

The initial approach applied in Phase 2 is developing a short-term vision which is aligned with the long-term vision by way of the backcasting approach first developed by Ackoff *et al.* (2012:35). Next, a system analysis is carried out where outputs of Phase 1 are evaluated and considered in the analysis from an ecosystem perspective (inside-out and outside-in). Idealised design and interactive planning take the process further, where technology assessments and analysis are done among the participants in a co-innovation participative process.

The technology assessment co-innovation process is primarily a divergent thinking method used to develop creative ideas through exploration. The process is free-flowing and creative and is a non-linear approach. The application of the S-curve is helpful in this phase as it indicates the rate of change of the technology through the various stages of a technology life cycle and when new and disruptive innovations (transition points) could enter the market (Loorbach and Van der Lindt, 2007:21). The following approach is proposed:

#### 7.3.3.1 Idealised design and interactive planning

The application of idealised design through interactive planning was first proposed by Ackoff *et al.* (2012:35), and it defined three essential principles of participation, continuity, and holism in the interactive planning process. The interactive planning component (Ackoff *et al.*, 2012:35) follows a multi-directional system analysis perspective for each timeframe (current reality, short, medium and long-term) in that the various system environments (operational, transactional and contextual) are consistently undergoing analysis in identifying patterns, relationships and risks from a technology complexity perspective (i.e. PESTLE analysis etc.) (propositions 5, 6, 7, 11 and 12).

Secondly, within the interactive planning approach, the TIPS framework is constantly being integrated to ensure that agility, alignment, and engagement are continually embedded in the process. Thirdly, the vision development in the idealised design phase is based on a normative approach and is defined for each state (short-, medium- and long-term) in the system analysis and idealised design process.

#### 7.3.3.2 Technology resilience

Technology resilience testing is the foundation of the conceptual technology roadmapping framework. The technology resilience capsule, as described in section 7.2, has four critical dimensions; 'the future', 'the now', 'the mind', and 'time', and are aligned with the three levels of organisational, operational, and the individual level, respectively (propositions 4 and 10).

A subset of the technology resilience framework is the application of technology risk profiling which considers three explicit types of risks associated with a specific technology. Firstly, emerging technology may have a market risk due to uncertainty regarding market size and customer acceptance.

Secondly, organisations can face technological risk due to technical viability, and thirdly, regulatory standards and organisational risks that consider internal capabilities, financial costs, and return on investments. These risk variables must be tested and resolved throughout the lifecycle (Day and Schoemaker, 2000); therefore, the ongoing analysis of technology resilience testing and the impact of the TIPS framework within the realm of people, innovation, technology, and systems is a vital and continuous process within the framework (proposition 13).

#### 7.3.3.3 Technology assessment and system hierarchy analysis

This analysis in the framework portrays the evolution of the technologies at the systems level to be explored and considered. The analysis follows an ideation approach where divergence (technology assessment) and convergence (system hierarchy) are applied cognitively.

The technology assessment phase is primarily a divergent thinking method used to develop creative ideas through exploration. The process is free-flowing and creative and is a non-linear approach. The application of the S-curve is helpful in this phase as it indicates the rate of change of the technology through the various stages of a technology life cycle and when new and disrupted innovations (transition points) could enter the market. The S-curve provides a deep understanding of the current and potential future technology trends, which are vital inputs into the roadmapping process and the competitive advantage of organisations.

The system hierarchy phase is where technologies are ranked in a detailed manner in levels of importance that meet the organisation's idealised state (vision). The thinking in this phase is predominantly convergent thinking, where technologies are ranked according to established rules and logical reasoning using existing methods and approaches applying priority matrix, option thinking, and other known methods. The output of this phase is the development of a short-term technology roadmapping plan aligned with the organisation's technology vision.

#### *7.3.4 Phase 3 - Medium-term systems perspective*

This phase follows the analytical approach similar to Phase 2, except that the analysis is on medium-term planning. The initial approach applied in this phase is developing a medium-term vision aligned with the organisation's long-term technology vision.

A critical aspect is to review the Phase 2 outputs and readjust and align accordingly in developing the medium-term vision. Idealised design and interactive planning, along with technology resilience profiling and testing, are carried out to ensure a robust resilience technology assessment and system hierarchy analysis. Finally, a technology assessment process is undertaken, leading to the development of a medium-term roadmap.

### *7.3.5 Phase 4 - Long-term systems perspective and systems integration*

In the final phase, the analysis of the long-term vision, developed in the preliminary phase, is applied in a systems analysis which considers the ecosystem in terms of the long-term operational and ecosystem landscape. It is followed by the technology assessment process for the final phase, where technology options for the long-term vision are proposed.

The crucial stage of this phase is when the participants integrate all the outputs in the roadmapping process by applying idealised design and interactive planning, forming part of the system integration analysis. It is an important stage in the roadmapping process, as it evaluates, reviews, incorporates, and adjusts all the outputs from the various phases into a detailed implementable technology roadmapping plan (idealised design plan) incorporating a comprehensive technology resilience profiling plan. The following stages are proposed:

#### 7.3.5.1 Review and critique the roadmap

Peer review through each phase of the technology roadmapping assumptions and deliverables through a thorough consultation process with stakeholders.

#### 7.3.5.2 Review and update

As described in Chapter 1, the work of Brinker (2016:12) has shown that organisations change at a logarithmic rate which is considerably slower than that of technology, which increases exponentially. Brinker (2016:12) proposes that the law captures organisations' most significant challenge of the decade in managing a comparatively slow and reactive organisation in a fast-changing technological world. Thus, technology roadmaps must be seen as living documents which require constant revision, development, and ongoing modifications to safeguard an organisation's ability to remain competitive and sustainable.

#### 7.3.5.3 Benefit realisation

Implement a plan to monitor, measure, and report tangible and intangible benefits (benefits realisation) of the technology implementation strategy and execution proposed in the technology roadmapping framework (proposition 9). The process that is required is the following:

1. Develop and design a plan to monitor and evaluate appropriate tangible and intangible benefits metrics.
2. Implement the monitoring plan.
3. Collect and evaluate data points for consistency and accuracy.
4. Run the benefits realisation model and report.

Benefit realisation offers the organisation a framework to simplify the execution phase by ensuring that the technology implementation plan is measurable. The value of the process is that it gives organisations the means to define and measure success.

Last but not least, in this phase, it is essential to note that in transition management theory, when considering complex systems, the implementation plan developed from the resulting technology roadmapping process requires a high degree of agility and flexibility to the changing ecosystem landscape (Loorbach *et al.*, 2017:626). However, more importantly, this agility and flexibility will allow organisations to respond rapidly to changes (both in timing and technology) as new data become available. Therefore, the technology roadmap must be perceived as a living document, and the continuous need for organisations to review, adapt, and update all phases of the process is imperative in order to stay relevant and remain competitive.

## **7.4 Contribution of the study**

The contributions of this research are multi-dimensional in terms of the technology roadmapping literature and its application. The literature has demonstrated that 'meso-level' roadmapping models and practices have not yet been adequately addressed by research and practice.

The first theoretical contribution relates to the development of a new 'third' generation

technology roadmapping approach which integrates the critical consideration of technology resilience with complex systems theory at all levels of the system environment (operational, transactional, and contextual) simultaneously for the current reality, short, medium and long-term time scales. This approach complements the current roadmapping approaches and enhances the methodologies and practices of the earlier generation roadmaps. Integrating system analysis and technology resilience into a conceptual technology roadmapping framework is a unique approach to developing an enhanced new roadmapping approach.

From the literature, several frameworks have alluded to the concept of systemic integration and complex systems theory as the basis for technology roadmapping (Kamtsiou, 2016:106; Letaba *et al.*, 2017:15). However, no known study integrates systems theory and technology resilience in the technology roadmapping framework.

The second theoretical contribution relates to integrating idealised design and systems analysis at each temporal phase of the roadmapping process. The idealised design and interactive component follow a multi-direction systemic perspective for each timeframe (current reality, short, medium, and long-term) in that the various environments (operational, transactional and contextual) are constantly undergoing analysis in terms of technology patterns recognition relationships and complexity.

The alignment of the Da Vinci TIPS framework in terms of agility, engagement, and alignment in the idealised design process is a unique application to the overall robustness of the roadmapping framework (Da Vinci Business School, 2022:15). In addition, it considers the characteristics of collaboration, cooperation, and coordination as critical constructs in developing a resilient technology roadmapping framework.

The third theoretical contribution relates to the ability of the framework to include and integrate benefit realisation value across the framework's various time phases (short, medium and long-term). The inherent importance of this inclusion is that it gives organisations the means to define and measure success almost continuously throughout the various process phases of the framework.

However, the inclusion of this approach has yet to be identified in any known study on

technology roadmapping.

In addition to the theoretical contributions, the conceptual technology framework proposed in this study can be considered an approach to address the system complexities organisations encounter related to technological risk and sustainably. The central foundation of the framework is the inclusion and integration of technology resilience with systems analysis for each phase, thus reducing the probability of failure for future technology decisions.

The systems approach can be counter-intuitive to the many current reductionist approaches to technology roadmapping based on a compressed market landscape, product, and technological layer. The framework proposed is founded on the premise of the assimilation of theories described in Chapters 2 and 3. It takes on the form of constant integrations, relationships, interconnectivity, and continuous feedback loops of the subsystems with the various components within the framework of systems complexity.

The unique characteristic is that the technology framework is multi-functional both in the vertical and horizontal planes and interacts in a non-linear manner. Thus, the roadmapping framework proposed could lay an enduring foundation for organisations for an alternative and more robust system and enhanced resilient approach to technology roadmapping.

## **7.5 Return on investment**

### *7.5.1 Personal ROI*

The quantum of the work entailed in completing this doctorate was enormous, and it engulfed the researcher's life over several years. The researcher's journey was a remarkable exploration into the world of technology management across many continents and cultures. The researcher's personal return on investment developed dramatically through the integration and understanding of cross-cultural forces globally in the many ways organisations viewed the ecosystem from a technological management perspective. The researcher now sees the world through very different

lenses, and his thinking has changed immensely regarding the systemic interrelationships between organisations, humanity and technology. The researcher now has the confidence to share his experiences, knowledge and ideas with colleagues, technologists and organisations in supporting them in the various approaches and applications in technology roadmapping.

### *7.5.2 Organisational ROI*

The organisation has adapted to a systemic and holistic approach to strategically managing technology, roadmapping processes and technology foresight studies. In addition, the organisation appointed the researcher as an Emeritus Advising Chair and has invited him to take on the chairmanship role in leading the organisation in a global electricity technology foresight study. The researcher has noted that the organisation is moving towards a more resilient thinking and sustainable enterprise by adopting an ecosystem perspective towards technology futures.

### *7.5.3 Societal ROI*

The foundation for societal return on investment is based on the systemic understanding that a delicate balance exists between the ecosystem and technology application and diffusion. The ability to fully comprehend and understand the interconnectivity and relationships between our ecosystem and technology is fundamental for our planet's survival. For society to function at its optimum, we need people to think at various levels of consciousness and to remain engaged, agile and aligned with our ecosystem continuously. This transformation within individuals will lead to the transformation of organisations and concurrently to the transformation within societies. Society's social behaviour impacts economic activities and the future technological revolution of the planet.

## **7.6 Limitations of the study**

The study's limitations became apparent as the data collection and analytical procedure commenced. Notwithstanding this study's contributions, several limitations

have been identified. The conclusions drawn from the analysis and results should therefore be seen in the context of the boundaries of a mixed method design research methodology.

The first limitation of this study relates to the nature of a qualitative study which requires in-depth analysis of a limited number of respondents. The member involvement in the first focus group workshop was 25% of the potential members who could have participated. The second focus group workshop had a sample size of 40%, an improvement from the first workshop. The qualitative survey had a response rate of 43%, indicating an increasing trend. A qualitative study does not generally require representativeness; however, the research would have benefited from a larger sample of the total IRO membership.

It is important to note that these workshops were held in various parts of the world, and as such, travel budgets and accessibility were extremely restrictive under the electricity utility budget constraints.

The second limitation of the study relates to the complex nature of the systems approach to technology roadmapping. As noted in some responses, the participants and respondents may not have fully understood the various factors and relationships impacting organisational processes and world views. Thus, the type of research design attempted in this study endeavoured to adopt an agile approach to which the respondents could express multiple views and discussions in an open-ended manner.

The third limitation of this study was related to the IRO quantitative survey study with a relatively small sample size ( $N=14$ ) which made it problematic to draw statistical inferences from the dataset regarding relationships between the variables outside of a correlation analysis. According to Chow *et al.* (2003), a dataset of at least 100 participants is required to successfully define relationships between the variables of interest. For this reason, results were not considered in the final analysis due to the relatively small sample size. Nevertheless, the analysis of the dataset indicated that saturation had been achieved.

## **7.7 Recommendations for further research**

As described in Chapter 6, the findings of this study have strongly suggested that technology resilience and organisational resilience are regarded as the most critical drivers in the technology roadmapping developmental process. Thus the area of further research proposed is to explore the development of a practical implementation technology resilience model in order to simulate and better understand the nonlinear behaviour of complex ecosystems in the technology roadmapping process.

Furthermore, it is suggested that the resilience model would significantly enhance an organisation's ability to develop a more robust planning approach for technology decisions.

## **7.8 Conclusion**

As demonstrated during this study, it sought to provide new insights into issues related to the technology roadmapping processes, design, and practice. The study proposes an enhanced conceptual technology roadmapping framework that simultaneously integrates the critical considerations of technology resilience with complex systems theory at all ecosystem levels. A key finding from the study was that under COVID-19 conditions, technology resilience was seen as the most critical element in defining future technology applications and, thus, technology roadmapping methodologies.

The unique characteristic is that the conceptual framework is multi-directional both in the vertical and horizontal planes and interacts in a non-linear manner and where technology resilience is considered a critical building block in the decision-making process. The technology roadmapping framework takes on the form of continuous systems integration and feedback loops of the sub-systems within the framework's various components. The framework requires that system environments constantly undergo systems analysis, scrutiny, and transformations regarding technology patterns recognition, relationships, complexity and resilience.

The study aimed to make a theoretical contribution to the current roadmapping approaches by developing a conceptual technology roadmapping framework that would create significant value for long-term technology sustainability for electricity utilities. This is particularly critical with respect to the processes of technology applications, strategic technology planning, risks, and implementation.

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# APPENDICES

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## Appendix 1: Solicitation letter

Gregory Tosen  
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South Africa  
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IRO Representative  
(Title)  
(Organisation)  
(Address)

14 January 2018

Dear Sir,

**Re: Request for Approval to undertake Focus Group Workshops with Members of the IRO**

My name is Greg Tosen, and I am currently a PhD candidate at the Da Vinci Institute for Technology Management in Johannesburg, South Africa. I am presently undertaking my thesis analysis titled "An Alternative Systemic Conceptual Framework for Technology Roadmapping: An Electricity Utility Perspective". As part of this research, I would like to undertake an industry-wide analysis by way of focus group meetings with IRO members, which will examine and explore current technology roadmapping practices and methods and the associated strengths and weaknesses in the current practices of technology roadmapping. Due to your global membership base, I seek your approval to undertake morning workshops at the next three Annual General Meetings.

The nature of the workshops will be to obtain related views and information on current trends, obstacles, views, reflections and approaches to current technology roadmapping methodologies and practices. All the data obtained will only be reported in an aggregated form and does not identify any information about the member. The data collected from the workshops will not include any proprietary information or details that would enable member organisations to be identified by name or location. Further, all discussions and responses will be considered confidential and will thus not be released, shared or published.

If approval is granted, I will set up an appropriate time to schedule a meeting with you to discuss an approach we can collectively consider for the workshops.

Thanking you for your consideration.

Yours sincerely,

*G R Tosen*

Gregory Robert Tosen  
The Da Vinci Institute for Technology Management  
Student Researcher  
Email: [greg@davinci.ac.za](mailto:greg@davinci.ac.za)

## Appendix 2: Introductory quantitative survey questions for Brussels and Berlin focus group participants

1. Have you ever participated in a technology roadmapping (TRM) process for your organisations?

Yes		No	
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2. Do you have experience in technology roadmapping (TRM) in terms of future technology requirements(>10yrs)?

Yes		No	
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3. How long have you been involved in technology roadmapping activities?

< 1 year	
> 1 & < 4 years	
> 3 & < 6 years	
> 5 & < 8 years	
> 7 & < 10 years	
> 10 years	

4. Where did you contribute and participate, and what was your role in the technology roadmapping exercise?

Current Organisation	
Previous Organisation	
Other – please specify	

5. What was the planning horizons (in years) for your organisation's technology roadmaps?

Short-term (1- 5 years)	
Medium-term (5 -10 years)	

Long-term (10- 20 years)	
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**6. In the technology roadmap process, what was the primary motivation for undertaking the exercise?**

To contribution to:

Research and development	
Operational asset management/performance	
Process development	
Product development	
Market development	
Customer requirements	
Other – e.g., understanding - please specify	

**7. Based on the above question, what was the likely impact of these technological outcomes on?**

Operational cost efficiency	
Research capacity development	
Manufacturing capacity development	
Process capacity development	
Market competitiveness	
Global Competitiveness	

Social impact (nationally)	
Economic impact (nationally)	
Environmental sustainability	
Political alignment	
Other – please specify	

**8. What were the main positive factors that influenced the technology roadmap outcomes? (1= least important and 5=most important aspect)**

	1	2	3	4	5
Enhanced research and development capability and funding					
Improved innovation culture					
Enhanced technical and engineering capability					
Expanded local and international collaboration					
Improved executive support and buy-in					
Increased entrepreneurial culture					
Social accountability					
Other – please specify					

**9. What were the main adverse factors that influenced the technology roadmap outcomes? (1= least important and 5=most important)**

Loss of research and development capability					
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Decrease in funding					
Weak innovation culture					
Lack of technical and engineering capability					
Lack of local and international collaboration					
Decline entrepreneurial culture					
Lack of social accountability					
Other – Please specify					

### Appendix 3: Quantitative survey results for the Brussels focus group participants

1. Have you ever participated in a technology roadmapping (TRM) process for your organisations?

Yes	(16)100%	No	(0)
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2. Do you have experience in technology roadmapping (TRM) in terms of future technology requirements(>10yrs)?

Yes	(15)94%	No	(1)6%
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3. How long have you been involved in technology roadmapping activities?

< 1 year	0
> 1 & < 4 years	(2)13%
> 3 & < 6 years	(3)20%
> 5 & < 8 years	(5)33%
> 7 & < 10 years	(4)27%
> 10 years	(1)7%

4. Where did you contribute and participate, and what was your role in the technology roadmapping exercise?

Current Organisation	100% - technology advisor, system grid expert, nuclear expert, transmission advisor, generation expert in the area of combustion research, environmental advisor, gas consulting expert, turbine expert, pollution control advisor, distribution network, systems operator,
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	renewable energy advisor
Previous Organisation	n/a
Other – please specify	n/a

**What was the planning horizons (in years) for your organisation’s technology roadmaps?**

Short-term (1- 5 years)	(16)100%
Medium-term (5 -10 years)	(16)100%
Long-term (10- 20 years)	(9)56% mainly R&D Institutes and Manufactures

**5. In the technology roadmap process, what was the primary motivation for undertaking the exercise?**

To contribution to:

Research and development	15%
Operational asset management/performance	60%
Process development	10%
Product development	5%
Market development	
Customer requirements	2%

Other – e.g., understanding - please specify	3%
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**6. Based on the above question, what was the likely impact of these technological outcomes on?**

Operational cost efficiency	70%
Research capacity development	10%
Manufacturing capacity development	5%
Process capacity development	5%
Market competitiveness	
Global Competitiveness	
Social impact (nationally)	
Economic impact (nationally)	5%
Environmental sustainability	5%
Political alignment	
Other – please specify	

**7. What were the main positive factors that influenced the technology roadmap outcomes? (1= least important and 5=most important aspect)**

	1	2	3	4	5
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Enhanced research and development capability and funding			5%	85%	10%
Improved innovation culture			75%	20%	5%
Enhanced technical and engineering capability		20%	50%	30%	
Expanded local and international collaboration			70%	30%	
Improved executive support and buy-in			80%	20%	
Increased entrepreneurial culture		20%	60%	15%	5%
Social accountability	20%	20%	60%		
Other – please specify					

**8. What were the main adverse factors that influenced the technology roadmap outcomes? (1= least important and 5=most important)**

Loss of research and development capability		20%	60%	20%	
Decrease in funding			10%	80%	10%
Weak innovation culture	40%	20%	30%	10%	
Lack of technical and engineering capability			60%	30%	10%

Lack of local and international collaboration	10%		80%	10%	
Decline entrepreneurial culture	30%	20%	50%		
Lack of social accountability	60%	10%	30%		
Other – Please specify	Note: The majority of the above ‘the lack of’ is due to the restructuring of the R&D departments, people etc which led to reduced funding in a number of areas.				

## Appendix 4: Quantitative survey results for the Berlin focus group participants

1. Have you ever participated in a technology roadmapping (TRM) process for your organisations?

Yes	(23)92%	No	2 (8%)
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2. Do you have experience in technology roadmapping (TRM) in terms of future technology requirements?

Yes	(23)92%	No	(2)8%
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3. How long have you been involved in technology roadmapping activities?

< 1 year	(2) 8%
> 1 & < 4 years	(1) 4%
> 3 & < 6 years	(2) 8%
> 5 & < 8 years	(6) 24%
> 7 & < 10 years	(6) 24%
> 10 years	(8) 32%

4. Where did you contribute and participate, and what was your role in the technology roadmapping exercise?

Current Organisation	100% - technology advisor, system grid expert, nuclear expert, transmission advisor, generation expert in the area of combustion research, environmental advisor, gas consulting expert, turbine expert, pollution control advisor, distribution network, systems operator,
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	renewable energy advisor
Previous Organisation	n/a
Other – please specify	n/a

**5. What was the planning horizons (in years) for your organisations technology roadmaps?**

Short-term (1- 5 years)	(25)100%
Medium-term (5 -10 years)	(25)100%
Long-term (10- 20 years)	(20)80% mainly R&D Institutes and Manufactures

**6. In the technology roadmap process, what was the primary motivation for undertaking the exercise?**

To contribution to:

Research and development	15%
Operational asset management/performance	45%
Process development	
Product development	5%
Market development	
Customer requirements	10%

Other – e.g. understanding - please specify	25% Political & regulatory requirements and improved global concerns related to future energy transition.
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**7. Based on the above question, what was the likely impact of these technological outcomes on?**

Operational cost efficiency	40%
Research capacity development	20%
Manufacturing capacity development	5%
Process capacity development	5%
Market competitiveness	
Global Competitiveness	
Social impact (nationally)	5%
Economic impact (nationally)	
Environmental sustainability	10%
Political alignment	15%
Other – please specify	

**8. What were the main positive factors that influenced the technology roadmap outcomes? (1= least important and 5=most important aspect)**

	1	2	3	4	5
Loss of research and development capability	10%	10%	50%	20%	10%
Decrease in funding			50%	40%	10%
Weak innovation culture	40%	20%	30%	10%	
Lack of technical and engineering capability	10%	10%	50%	30%	
Lack of local and international collaboration		20%	60%	10%	10%
Decline entrepreneurial culture	20%	20%	50%	10%	
Lack of social accountability	20%	20%	30%	20%	10%
Other: Political alignment	10%	20%	50%	10%	10%

**9. What were the main adverse factors that influenced the technology roadmap outcomes? (1= least important and 5=most important)**

	1	2	3	4	5
Loss of research and development capability	10%	10%	50%	20%	10%

Decrease in funding			50%	40%	10%
Weak innovation culture	40%	20%	30%	10%	
Lack of technical and engineering capability	10%	10%	50%	30%	
Lack of local and international collaboration		20%	60%	10%	10%
Decline entrepreneurial culture	20%	20%	50%	10%	
Lack of social accountability	20%	20%	30%	20%	10%
Other: Political alignment	10%	20%	50%	10%	10%

## Appendix 5: Brussels and Berlin focus group open-ended questions

Questions	Response
<b>Technology Roadmap development process</b>	
1. Who sponsored the development of TRM?	
2. In the initial planning phases, were structures put in place for the development of technology roadmaps?	
3. To what degree did the sponsor/s have a significant impact on the methodology applied during the TRM development?	
4. In the TRM analysis, did you apply an exploratory or normative approach and if so, how was the approach adopted?	
5. What were the main strategic factors that influenced the approach to technology roadmapping outcomes in your organisation?	
6. In the TRM process that you participated in, how important were the operational drivers that influenced the analysis?	
7. What was the resultant impact of the operational drivers on the technology selection process?	
8. When considering the above operational issues in your roadmapping approach what additional areas would you consider as a key driver to your roadmap and why?	
9. When considering the outcomes in your roadmapping process, what were the critical drivers that influenced your analysis?	
10. What was the resultant impact of the meso/transactional environment on the technology selection process?	
11. How critical was the contextual environment in your analysis, and what macro considerations were taken into account?	
12. What was the resultant impact of the macro drivers on the technology selection process?	
13. When considering the operational issues in your TRM process what are the key issues and challenges that you need to build into your roadmap with respect to renewables and why?	
14. How long did your organisation's development roadmapping process take from inception to completion of the final product?	
<b>The strategic role of TRMs</b>	
15. Was the TRM process integrated into other internal strategies, and if so, how were they interrelated?	
16. In the development of TRMs, where they integrated and	

developed with external stakeholders, e.g. Customers, regulators etc. and if so, how were they related?	
17. Was there adequate effort and commitment shown in updating the TRM?	
18. How has your organisation's executive support influenced the success or failure of the TRM process and implementation?	
19. How often do you update your TRM?	
<b>Critical success factors of TRMs</b>	
20. Have you developed critical success factors (CSF) for your TRM implementation?	
21. What are the critical success factors (CSF) for the success of TRMs?	
22. How do you go about monitoring, evaluating and reporting the success factors?	
23. Do you believe there was value in undertaking the TRM?	

## Appendix 6: Brussels focus group responses

<b>Technology Roadmap development process</b>	
<b>1. Who sponsored the development of TRM?</b>	<ul style="list-style-type: none"> <li>• It generally starts within the R&amp;D division of the company, which in some cases is centrally located with corporate or, in other cases, a decentralised function.</li> <li>• Very seldom, if not at all, does technology strategy/TRM get initiated at the executive level.</li> <li>• It is, in most cases, a bottom-up approach developed by a technologist in support of and for organisational benefits.</li> <li>• It is seldom initiated by the CEO and executive in most cases; however, in some instances, the appropriate R&amp;D executive may well request the development of a TRM process.</li> <li>• Within the Manufacturing business, we look at market requirements in terms of potential customer requirements, and then we develop technology roadmapping processes in either meeting the requirements in terms of new product development or incremental improvement of current technologies.</li> </ul>
<b>2. In the initial planning phases, were structures put in place for the development of technology roadmaps?</b>	<ul style="list-style-type: none"> <li>• Not initially, the lead came from the technology staff; once the process was started, then we developed as we went along structures. It was extremely difficult at first as people in the organisation did not have the time or the inclination as they were very busy with operational issues. We then had to request from our executive to discuss our process and aim with other executives from the various divisions within our organisations to make time available for meetings, interactions and idea generation regarding input into the technology roadmap process. The structures were initially not well developed, and as such, the process was hampered. Not all in the organisation were involved, thus making the final outcome not fully appreciated. This resulted in the technology roadmap not fully being accepted by various parts of the business. We believe if there had been strong CEO and executive support, the process would have been a lot more accepted and would have had much more strategic value to the business and the line divisions.</li> <li>• Our organisation which is an R&amp;D-only business, structures were well developed in terms of the process. There was a high-level commitment which made the process that much easier to manage in terms of our time frames and final outputs.</li> </ul>
<b>3. To what degree did the sponsor/s have a significant impact on the methodology applied during the TRM development?</b>	<ul style="list-style-type: none"> <li>• Initially, the sponsors (in general) in instances when we had one, in many cases, tried to influence the direction of the process and methodology. In many cases, succeeding and all it became was the sponsors/executives/CEO's view of what the outcome should be of the technology roadmap from a technological perspective. In this case, at times much dissatisfaction to the developers.</li> <li>• Yes, so in most of the cases, sponsors did have an impact on the eventual outcome</li> </ul>

of the TRM and, thus, on the approach and methodology
<b>4. In the TRM analysis, did you apply an exploratory or normative approach and if so, how was the approach adopted?</b>
<ul style="list-style-type: none"> <li>• In most cases, the exploratory approach was used i.e. scenarios were developed as possible futures. These futures were developed in-house, based on the scenarios developed by the technical experts in most cases.</li> <li>• Minimal use of normative approach was used.</li> </ul>
<b>5. What were the main strategic factors that influenced the approach to technology roadmapping outcomes in your organisation?</b>
<ul style="list-style-type: none"> <li>• Operational issues are key to the survival of our business. We focus on our current assets in terms of quality of supply. So our key driver in our approach to roadmapping is operational performance and, thus, asset management.</li> <li>• Linked to this is the driver of regulatory requirements.</li> <li>• The second key driver in roadmapping is to focus on regulatory requirements such as air pollution.</li> <li>• The driver is looking at developing strategic partnerships so that we can share risks and costs. Partnerships and JV are difficult to manage.</li> <li>• In terms of the long-term future, we then look at the introduction of renewables as climate change will be something that we need to consider in the next 10 to 20yrs. We cannot consider it now as we have extremely expensive assets, and their lifetime is around 40 to 60 yrs. This includes gas, coal, and nuclear energy plants.</li> </ul>
<b>6. In the TRM process that you participated in, how important were the operational drivers that influenced the analysis?</b>
<ul style="list-style-type: none"> <li>• Operational drivers are extremely critical and imperative in terms of business sustainability and shareholder value.</li> <li>• Critical priority lists were developed in terms of the operational drivers/ business efficiency, which were ranked as key focus areas of technology development.</li> </ul>
<b>7. What was the resultant impact of the operational drivers on the technology selection process?</b>
<p><b>A number of priority areas were identified:</b></p> <ul style="list-style-type: none"> <li>• Operational issues (asset management), i.e. business efficiency, was the most important driver as it was to ensure sustained and optimal business service and thus revenue to our shareholders, thereby driving shareholder value.</li> <li>• So the primary focus and resultant impact were to maintain consistent service delivery by ensuring appropriate technology usage at the least cost.</li> <li>• It is important to note that the energy business is a long-term conservative business as we have run our plants for 40 years or more. Thus when making technology decisions, we need to be conservative in our approach. You must note that the energy business is a multi-billion dollar business, and as such, we are extremely risk-averse.</li> </ul>

**Some of the key priority areas are given below:**

**Priority level 1**

Electric Power Systems are a challenge from an operational perspective in terms of the following key aspects from an operational perspective:

- Integration of large-scale and centralised renewable generation - A10
- Asset Management & Modernization - A15
- Long-distance and high-capacity power transmission - A9
- Strengthening and restructuring facilities, equipment and grid operations - A1

***Technical Issues***

- Improving stochastic models for short and mid-term operations planning. Assuring security, stability and quality of supply - A10
- Ageing infrastructure, need to prioritise repair/Replacement - need M&D and condition-based maintenance - A15
- EHV/UHV AC and DC transmission technology, equipment manufacturing and construction, and operation of transmission lines - A9
- Strengthening wide-area coordination (this would include items like improved network control, reducing losses, etc.) - A1

- **Priority Level 2**

- Electric Power Systems from an operational perspective – the challenge
- Maintenance and Replacement of electric power system facilities and equipment – A1 & A10
- Resilience – A15
- Bulk interconnected power grid security and stability and prevention of cascading failures – A9

***Technical Issues***

***Development of joint multilateral expertise in advanced asset management technologies leading to:***

- Faster, more reliable 'self-healing' schemes to make responding to natural and other disasters; different monitoring & control techniques
- Increasing network stability and risk-based management and control

**Operational issues (asset management), i.e. business efficiency**

**Priority Level 3**

- Electric Power Systems – the challenge
- Strengthening and restructuring facilities, equipment and grid operations – A10
- Increasing distributed generation – A15
- Integration of large-scale and centralised renewable generation – A9
- Power Plants – the challenge
- Maintenance of existing power plants - A1

### ***Technical Issues***

- Reducing network losses
- More difficult to manage in primarily central generation control schemes; new grid systems may be primarily distributed in emerging markets
- Large-scale and centralised renewable generation (such as wind and solar generation) and its integration within the business are important
- Improve current maintenance approaches

### **Operational issues (Asset Management), i.e. business efficiency Priority 4**

- Electric Power Systems – the challenge
- Strengthening and restructuring facilities, equipment and grid operations – A10
- Integration of renewables – A15
- Strengthening and restructuring facilities, equipment and grid operations – A9
- Strengthening and restructuring facilities, equipment and grid operations

### ***Technical Issues***

- Strengthening wide-area coordination
- Variability leads to various challenges
- Making dispatching and ICT more intelligent
- Establishment of next-generation ICT infrastructure for further linkage of related parties

### **Operational issues (Asset Management), i.e. business efficiency Priority 5**

- Electric Power Systems
- Assessment of the impact of initiatives and other measures to promote the large-scale introduction
- Integration of distributed generation
- Thermal Generation
- Integration of renewables

### ***Technical issues***

- Manage the impact of more variable operation - improved M&D and condition-based maintenance
- Integration of distributed generation and micro-grid with advanced, flexible and interactive distribution grid
- Retail (customer)

### **Responding to changes in supply and demand Priority 5**

- Renewable Energy (Climate change)
- Assessment of the impact of initiatives and other measures to promote

large-scale introduction - A15
<p><b>8. When considering the above operational issues in your roadmapping approach, what additional areas would you consider as a key driver to your roadmap and why?</b></p>
<ul style="list-style-type: none"> <li>• As mentioned earlier, we need to focus on operational issues (asset management) as this is the most important driver we need to consider in our current business when considering roadmapping. It's all very well focussing on other issues however our business is supplying quality electricity to our customers thereby achieving shareholder value.</li> </ul> <p><b>Some key additional drivers and areas that were considered in the TRM process:</b></p> <ul style="list-style-type: none"> <li>• Electric Power Systems</li> <li>• Long-distance and high-capacity power transmission. EHV/UHV AC and DC transmission technology, equipment manufacturing and construction, and operation of transmission lines. R&amp;D - UHV DC transmission system technology and equipment manufacturing</li> <li>• Strengthening system operation technology</li> </ul> <p><b>Making dispatching and ICT more intelligent leads to a critical R&amp;D focus in the following areas:</b></p> <ul style="list-style-type: none"> <li>• PMU-based bulk power grid wide-area situational awareness, decision-making and control</li> <li>• Power grid dispatching with high penetration of renewable generation (power flow control, reactive power compensation, active power and frequency regulation)</li> <li>• Economic operation of power system, adapting to optimised resource allocation of bulk interconnected power grid with various power sources (conventional power source, wind, solar and storage) in the context of the power market</li> <li>• Power grid-oriented new-generation information and communication network system construction (such as large-capacity all-optical fibre network, design of intelligent information and communication components)</li> <li>• Information and communication security defence system construction (security defence detection technology key management and isolation technology)</li> </ul>
<p><b>9. When considering the outcomes in your roadmapping process, what were the critical drivers that influenced your analysis?</b></p>
<ul style="list-style-type: none"> <li>• The most important drivers were the operational efficiencies of the business.</li> <li>• This means that if we could improve on the operational aspect of our business, the operational cost would decline, thus improving our review stream. Keeping the technical side of our business well-run, e.g. managing our assets, would have a huge impact on our business from a financial</li> </ul>

<p>perspective and operational perspective.</p> <ul style="list-style-type: none"> <li>• Of course, regulatory considerations are critical in meeting the requirements of our regulator. It was our view that these requirements be integrated into our operational and asset management programme.</li> <li>• We also consider our current skill set in terms of critical drivers, and these certainly influence our approach to the analysis.</li> </ul>
<p><b>10. What was the resultant impact of the meso/transactional environment on the technology selection process?</b></p>
<ul style="list-style-type: none"> <li>• As mentioned before, the role of the regulator is important, and we need to ensure that we meet the minimum requirements in our operations.</li> <li>• We did review other utilities; however, because of the current state of affairs in your business globally, the focus was clearly on how we could improve our business from an operational perspective.</li> <li>• Of course, by making our business more efficient, it made an impact on our customers.</li> </ul>
<p><b>11. How critical was the contextual environment in your analysis, and what macro considerations were taken into account?</b></p>
<ul style="list-style-type: none"> <li>• It was not as critical as the operational environment. Yes, we are aware that environmental issues are important, BUT as you are aware, our power plants are built to last 40 to 50 years. Thus there is no way we can upgrade or change our current fleets of power plants to meet potential future emission targets. It is just way too expensive, and thus we look at improving efficiencies as a mechanism of improvement.</li> <li>• For our state-owned institutions, the role of governments and politics has a huge impact on how we run our business. In many cases, the impact can be negative, as politicians have no idea of how to run energy plants.</li> <li>• Governments continually interfere in state-owned organisations to a point where it can have huge technology negative impacts on the business and the country.</li> <li>• Technological development was critically evaluated and considered in our process as a key driver</li> </ul>
<p><b>12. What was the resultant impact of the macro drivers on the technology selection process?</b></p>
<ul style="list-style-type: none"> <li>• In some cases, it hampered the development of technology as our shareholders (governments etc.) did not always buy into the technology selection outcomes.</li> <li>• This resulted in the lack of funding, skills and technology adaption. Shareholders were more likely to fund operational linked improvements rather than medium to long-term benefits from a technology perspective.</li> </ul>
<p><b>13. When considering the operational issues in your TRM process, what are the key issues and challenges that you need to build into your roadmap with respect to renewables and why?</b></p>
<ul style="list-style-type: none"> <li>• Renewables are something that we need to consider in the long-term. We will be forced sometime in the future through government policy to consider (political environment). However, it is important to note that integrating renewables into our current system is extremely problematic</li> </ul>

and, as such, will incur additional costs and major problems in our business if we are forced to apply. Power plants are extremely costly, and considering the life of the plant. Current fossil and nuclear plants must take preference over new technologies purely from a cost perspective.

**Key operational considerations that we will have to take into account**

**when considering renewable energy:**

- Renewables are something that we need to consider in the long-term. We will be forced sometime in the future through government policy to consider (political environment). However, it is important to note that integrating renewables into our current system is extremely problematic and, as such, will incur additional costs and major problems in our business if we are forced to apply. Power plants are extremely costly, and considering the life of the plant. Current fossil and nuclear plants must take preference over new technologies purely from a cost perspective.
- Key operational considerations that we will have to take into account when considering renewable energy:
  - Integration of large-scale and centralised renewable generation
  - Improving generation coordination within the business to cope with intermittence.
  - From an R&D perspective, we need to improve stochastic models for short and mid-term operations planning
  - Assuring security, stability and quality of supply.
  - From an R&D view Improving models to analyse harmonics and resonance issues in wind power plants
  - Assessment of the impact of initiatives and other measures to promote large-scale introduction. Market-oriented approach to attract investment in renewable generation is required to comply with clean energy goals
  - EHV/UHV transmission line construction using new materials, new equipment and new techniques
  - The utilisation of under-used resources, e.g. advanced geothermal: hot dry rock
  - Modelling and new simulation technology (such as parallel calculation, hybrid simulation, all-digital simulation and long-term and mid-term dynamic simulation) of power systems with new equipment (such as renewable generation, energy storage, VSC-HVDC)
  - Just to note some of the key challenges if and when we consider introducing Renewable generation:
    - Bulk interconnected power grid security and stability and prevention of cascading failures which leads to major technical issues of increasing network stability and risk-based management and control.
    - Thus from an R&D perspective, we have to spend funds researching:
    - Real-time monitoring, emergency control and fast restoration measures for the prevention of large-scale blackouts and cascading failures
    - Coordinate operation and control of EHV/UHV AC and DC hybrid grid

- Online and fast screening, risk assessment and decision control of potential grid failures
- Online assessment and measures adoption for voltage stability of power grid
- R&D and manufacturing of new relay protection devices used in new power grid equipment (such as series capacitor compensation on UHV line)
- Integration of large-scale and centralised renewable generation means that we have to introduce and consider large-scale and centralised renewable generation (such as wind power generation and solar generation) and its integration.
- Thus from an R&D perspective, we have to spend funds researching:
- High-precision numerical weather forecasting and power prediction for wind and solar generation
- Construction and simulation technology development of the wind-PV-storage test platform
- Analysis and evaluation of the impact of large-scale and centralised renewable power generation integration on the secure and stable operation of power system
- Effective accommodation and economical operation of large-scale and centralised renewable generation
- Coordinating control of renewable power generation and conventional power sources
- Offshore wind farms construction and IGBT-based HVDC network configuration technology and operation control
- Grid-level energy storage and its application
- Multi-level services -based on new dispatching technology (such as cloud computing, big data distributed storage and data mining, dynamic visualisation, smart analysis, control and optimisation)
- Integration of distributed generation and micro-grid with advanced, flexible and interactive distribution grid
- Distributed generation and micro-grid configuration, protection, and control technology and EMS
- Distribution grid energy storage technology and its application for accommodating renewable generation (wind power and PV generation)
- Impact of high infiltration of distributed generation on the existing distribution grid
- Improvement of power quality, reliability and self-healing of the distribution grid and loss reduction of the distribution grid
- Effective utilisation of DSM and Demand Response technology
- Construction and Deployment of an intelligent and interactive information collection system for power user consumption
- Strengthening and restructuring facilities, equipment and grid operations
- Energy storage: battery, pumped storage, compressed air, etc.





<p><b>14. How long did your organisation's development roadmapping process take from start to completion of the final product?</b></p>
<ul style="list-style-type: none"> <li>• It generally took around 12-18 months to come up with the final report. It then took a further six months to share with the organisation.</li> <li>• In some instances, it took much longer due to the fact that we had poor processes and that it became a 'political ball' within our organisation. This resulted in many cases that the final report never was completed and presented.</li> <li>• In many cases, because of generally a bottom-up approach, the process was started and never completed.</li> </ul>
<p><b>The strategic role of TRMs</b></p>
<p><b>15. Was the TRM process integrated into other internal strategies, and if so, how were they interrelated?</b></p>
<ul style="list-style-type: none"> <li>• In electricity utilities, in most cases, the TRM is not integrated into other organisational strategies. In some cases, there is a certain amount of integration</li> <li>• The view is that the TRM was developed by the researchers and scientists of the organisation, i.e. technocrats, and there it must stay. It was seldom integrated fully into the organisation's business model; however, recently, this is slowly changing in that issues related to technologies and the approach to energy transition to clean technologies are now becoming a key aspect in our strategic business plan and thus operating model.</li> <li>• The operational side of R&amp;D in some organisations would be considered a cost and not a value and thus had a major impact on the funding model of technology in the organisation. R&amp;D was generally seen as a cost, not a value.</li> <li>• In R&amp;D institutes, the TRM is always integrated into business plans and strategies as it was a key driver in terms of manufacturing and future development</li> </ul>
<p><b>16. In the development of TRMs, where they integrated and developed with external stakeholders, e.g. Customers, regulators etc. and if so, how were they related?</b></p>
<ul style="list-style-type: none"> <li>• No, in electricity utility organisations, it was done in-house with only in-house experts and staff.</li> <li>• We did not bring in external stakeholders.</li> <li>• In the R&amp;D institutes, customers were involved in the process. Mainly at the end of the process and feedback on the final TRM report.</li> </ul>
<p><b>17. Was there adequate effort and commitment shown in updating the TRM?</b></p>
<ul style="list-style-type: none"> <li>• There is no standard approach to updating the TRM in our organisation. Still undertaken in an unstructured manner; however, we note that this process has started to change due to the importance of appropriate clean technologies in the future.</li> <li>• General practice or process in place in updating. It varies from 2 to 4 years.</li> <li>• As an R&amp;D institute, we have a process and continuously look at technologies and would say we tend to update every 2 to 3 years</li> <li>• A key issue related to the updating of the TRM is that, in numerous cases, there is a lack of a clear implementation strategy</li> </ul>

<b>18. How has your organisation's executive support influenced the success or failure of the TRM process and implementation?</b>
<ul style="list-style-type: none"> <li>• Yes, executive supports the crucial for the success and role of the TRM.</li> <li>• Without executive support funding, rollout and implementation would not happen in the organisation.</li> <li>• Seldom do we apply a robust ROI of the TRM implementation and lack of learning and reflection on the value of the TRM to the organisation.</li> <li>• There is still a lack of disciplined execution process of the TRM, and this is due to the fact that there is no clear implementation plan along with the appropriate funding mechanisms.</li> <li>• In some cases, executives tend only to use the TRM for their own gain, and once the final report is done and presented, executives tend to move on to their next big project. However, there seems to be a change in this behaviour as the pressure for future clean technology for energy transition is becoming a key political key issue both nationally and globally.</li> </ul>
<b>19. How often do you update your TRM?</b>
<ul style="list-style-type: none"> <li>• Rarely, i.e. once off to 3 to 5 years. This is dependent on the organisation and the buy-in and acceptance of the executives.</li> </ul>
<b>Success factors of TRMs</b>
<b>20. Have you developed critical success factors (CSF) for your TRM implementation?</b>
<ul style="list-style-type: none"> <li>• As mentioned before, this is an area where we lack a robust approach in clearly defining the benefits realisation of the TRM implementation process.</li> <li>• Developing a robust ROI is difficult and seldom done.</li> <li>• There is no checklist on how and when we implement the TRM, and thus we are extremely weak in disciplined execution and reporting and evaluation of the TRM benefits.</li> <li>• We seldom do surveys with our internal customers and hardly ever with our external customers.</li> <li>• So there is very little focus on developing CSF or KPIs for TRM implementation.</li> </ul>
<b>21. What are the critical success factors (CSF) for the success of TRMs?</b>
<ul style="list-style-type: none"> <li>• As mentioned, very little CSFs developed TRM implementation.</li> <li>• As mentioned, we plan and develop the TRM report and then fail to develop appropriate CSF and ROI's</li> <li>• We are weak in this area, and we need to develop a process to improve in this area</li> </ul>
<b>22. How do you go about monitoring, evaluating and reporting the success factors?</b>
<ul style="list-style-type: none"> <li>• As mentioned above, in this area, we are extremely weak, as once we have developed the TRM, we feel that the job is done. Of course, this is not the case, and we need to improve in this area</li> </ul>
<b>23. Do you believe there was value in undertaking the TRM?</b>
<ul style="list-style-type: none"> <li>• Yes, we believe there is a major benefit to organisations in undertaking the TRM. However, you must note that we are part of the process of developing the TRM and thus believe it's an imperative.</li> <li>• It creates value from an efficiency perspective, is give the organisations a</li> </ul>

view of what technology they need to consider in the future as it focuses on operational performance and thus has a huge impact on the financial aspect of the business regarding financial saving and improved performance.

- It also has the potential to develop new innovative products and, at the same time create engineering and scientific skills and produce products that create value for the business.

## Appendix 7: Qualitative table of categories, codes and frequencies for the Brussels workshop

	Count	% Codes	Cases	% Cases
 Absorptive Capacity				
• Multidisciplinary	4	4,1%	1	100,0%
• Knowledge sharing	5	5,1%	1	100,0%
• Technology dispersion	2	2,0%	1	100,0%
 Critical elements of a TRM framework				
• Benefit realisation				
• Customer understanding	1	1,0%	1	100,0%
• Disciplined execution	1	1,0%	1	100,0%
• Disciplined Planning	6	6,1%	1	100,0%
• Executive buyin	2	2,0%	1	100,0%
• Organisational support	3	3,1%	1	100,0%
• Risk analysis	1	1,0%	1	100,0%
• Systemic practice	1	1,0%	1	100,0%
• World view				
 Organisational process obstacles				
• Arrogance	1	1,0%	1	100,0%
• Operational perspective	26	26,5%	1	100,0%
• Conservative				
• Customer ignorance	2	2,0%	1	100,0%
• Lack of disciplined execution	1	1,0%	1	100,0%
• Linear thinking	1	1,0%	1	100,0%
• Corporate politics - Lack of support	5	5,1%	1	100,0%
• Least cost technology	1	1,0%	1	100,0%
• Lack of Monitoring, reporting and evaluations	1	1,0%	1	100,0%
• Organisational ignorance	4	4,1%	1	100,0%
• Political interference	1	1,0%	1	100,0%
• ROI lacking	1	1,0%	1	100,0%
• Shareholder first	1	1,0%	1	100,0%
• Short-term strategic focus	5	5,1%	1	100,0%
• Silo mentality	5	5,1%	1	100,0%
• Sponser influence	3	3,1%	1	100,0%
 Critical constructs				
• Agility	1	1,0%	1	100,0%
• Climate change	2	2,0%	1	100,0%
• Environmental impact	1	1,0%	1	100,0%
• Strategic vision	1	1,0%	1	100,0%
• Organisational resilience	4	4,1%	1	100,0%
• Political environment	2	2,0%	1	100,0%
• Systems thinking	3	3,1%	1	100,0%

## Appendix 8: Berlin focus group responses

<p><b>Technology Roadmap development process</b></p>
<p><b>1. Who sponsored the development of TRM?</b></p>
<ul style="list-style-type: none"> <li>• The R&amp;D divisional executive of the company sponsors the TRM process It is a bottom-up approach developed by technologist in support of future technology developments.</li> <li>• It has been noted that in some cases it has been initiated by the CEO and executive. This has been mostly due to political pressure from national governments and the need to consider issues such as climate change, environmental issues and the need to lower the cost of electricity generation and the supply of electricity to the most poor and vulnerable in terms of rural electrification. However, in most cases the lead is taken from the appropriate technology specialist.</li> <li>• In the manufacturing business market requirements and to an increasingly environmental issues and climate change has become a key focus.</li> <li>• This is clearly headed up by our executive CEO etc. and the TRM is critical to our sustainability of our business and meeting our customers needs.</li> </ul>
<p><b>2. In the initial planning phases, were structures put in place for the development of technology roadmaps?</b></p>
<ul style="list-style-type: none"> <li>• Generally the lead comes from the R&amp;D/technology staff.</li> <li>• Planning and processes are structured and put in place.</li> <li>• Generally initially difficult to get traction and this delayed the TRM process.</li> <li>• The difficulty at first was that resources (both funding and people) were not appropriately allocated resulting in time delays..</li> <li>• The structures were initially not well developed and as such the process was hampered</li> <li>• This resulted in the technology roadmap not always been fully being accepted by various parts of the business.</li> <li>• In cases where the CEO and executive supported the process more acceptance and better integration across the business. This resulted in improved strategic value to the business and the line divisions.</li> <li>• Our organisation which is an R&amp;D only business, structures were well developed in terms of the process. There was high-level commitment which made the process that much easier to management in terms of our time frames and final outputs.</li> </ul>
<p><b>3. To what degree did the sponsor/s have a significant impact on the methodology applied during the TRM development?</b></p>
<ul style="list-style-type: none"> <li>• Initially the sponsors during the start of the programme had minimal impact/influence on the process and outcomes.</li> <li>• As the TRM process moved into outputs stages the involvement of the sponsors became more pronounced. It was seen as both positive and negative. In terms of trying to influence the direction of the outcomes.</li> <li>• Sponsors did have an impact on the TRM methodological process and thus</li> </ul>

at time the key outputs.
<b>4. In the TRM analysis, did you apply an exploratory or normative approach and if so, how was the approach adopted?</b>
<ul style="list-style-type: none"> <li>• In all cases the exploratory approach was use, i.e. scenarios, were developed as possible futures. These futures were developed in-house, however at times differed from the organisational scenario based on the scenarios developed by the technical experts in most cases.</li> <li>• Normative approach is seldom used in most organisations. I cannot remember ever using a normative approach – A11</li> </ul>
<b>5. What were the main strategic factors that influenced the approach to technology roadmapping outcomes in your organisation?</b>
<ul style="list-style-type: none"> <li>• Operational issues and plant flexibility are key to the survival of our business. Asset management is key in terms of quality of supply. So one of our key drivers is approach to roadmapping is operational performance and thus asset management.</li> <li>• Linked to this is the driver of regulatory requirements. This is linked to regulatory requirements related to environmental protection.</li> <li>• What is becoming a key driver as well is related to carbon emissions and the impact on climate change. So we are now looking at technologies that would reduce and minimise carbon emissions.</li> <li>• National Political pressure (government interference) is becoming a major issue and we have to react to this. This is in terms of government generation requirements in terms of national global climate signatories that our government have signed and approve regarding carbon emissions</li> <li>• Key driver linked to national political drivers is the role out of rural electrifications, this is mainly in developing countries.</li> <li>• Global pressure related to climate change in a key driver in the way we must generate power.</li> <li>• Customers and pressure group are also significantly impacting the way we view future generation and thus technology adaptation for the future.</li> <li>• A strong push in the way we look at future technologies that are sustainable and being able to meet the requirements of network integration. In addition, making power generation affordable and reliable at the same time.</li> <li>• Thus all aspects of renewables will be a key driver but at present we are looking a hybrid approach and that will still have to include coal, (fossil fuels) and nuclear.</li> </ul>
<b>6. In the TRM process that you participated in, how important were the operational drivers that influenced the analysis?</b>
<ul style="list-style-type: none"> <li>• Operational drivers are critical and imperative in terms of business sustainability, shareholder value and ensuring that there is a consistent availability of supply.</li> <li>• In terms of the operational drivers these were priorities in terms of future technology and costs.</li> <li>• The application of affordable electrification technologies in rural regions in terms of increasing access to our potential customers</li> </ul>

- Customer services offered by non-traditional actors might also impact the traditional business models

**7. What was the resultant impact of the operational drivers on the technology selection process?**

- In some cases it hampered the development of technology as our shareholders, did not always buy in to the technology selection outcomes.
- This resulted in the lack of funding, skills and technology adaption.
- Shareholders are more likely to fund operational linked improvements rather than medium to long-term benefits from a technology perspective. However, there is a move for shareholders to see the important of adapting business models to that of reducing carbon emissions.

**A1**

- Efficiency Targets - Energy is in surplus for 10 years ahead at least. Power balance is tight.
- Electrification Targets - On-going trend but developing slowly up until now. Might change in the near future. New government programme at the provincial level- 400 M\$ CAD- to promote the sales of 100,000 electric vehicles in the province.
- Other Targets - Integration of more renewable energy is a trend that might change significantly the business. Solar and Wind are getting close to parity with new Hydro.

**A2**

- Efficiency Targets - Energy consumptions per GDP: 16% below its 2010 level in 2015. 15% non-fossil fuel energy consumption, 10% natural gas and 62% coal consumption until 2020.
- Electrification Targets - Electrified railway length: 72 thousand km or 60% of the total railway length. Urban railway system: 10 thousand km by 2020. Electric vehicles: 0.5 million by 2015, 5 million by 2020
- Other Targets - Mainland China has 26 nuclear power reactors in operation, 25 under construction, and more about to start construction

**A3**

- Efficiency Targets - 50% energy consumption until 2050
- Electrification Targets - 7 millions of charging stations until 2030

**A4**

- Efficiency Targets - 50 % primary energy consumption until 2050; -25 % electricity consumption until 2050
- Electrification Targets - 1 million electric vehicles until 2020; 6 million electric vehicles until 2035
- Other Targets - Nuclear phase out until the end of 2022

**A5**

- Efficiency Targets - Very diverse situation; in GCC high consumption levels and increasing awareness on energy efficiency; selectively even specific targets, e.g. Dubai -30% energy consumption
- Electrification Targets - E-mobility not competitive; clear ramp up only at the end of the decade. Desalination will shift from heat based (multi stage

flash) to reverse osmosis (electricity based)

- Other Targets - Market interconnection is rather limited and expected to stay so for a decade or so, for political reasons. Nuclear new builds

A6

- Efficiency Targets - HKSAR Government is promoting Energy Efficiency and Conservation, e.g. on guidelines and incentives for buildings, air-conditioning, renewables
- Decarbonisation Targets - HKSAR Government is also working to reduce reliance on coal and shifting the fuel mix to more natural gas and nuclear generation, as well as promoting renewables
- Electrification Targets - HKSAR Government also promotes EV

A7

- Efficiency Targets - 17- 26% primary energy consumption reduction until 2050 with respect to 2010
- Electrification Targets - Doubling of electricity share on final consumption to reach the threshold of 38% until 2050
- Other Targets - Progressive reduction in relative and absolute weight of natural gas in favour of renewable

A8

- Efficiency Targets - 10% (compared to 2013) primary energy consumption in 2030. +1.5% (compared to 2013) electricity consumption in 2030. -17% (compared to BAU case) electricity consumption in 2030
- Electrification Targets - Share of electricity in final energy consumption (25% in 2013) up to 28% in 2030. Share of 'Next-generation vehicles' (hybrid, plug-in hybrid, electric, and fuel cell vehicles) in new car sales up to 50-70 % in 2030

A9

- Efficiency Targets - Reduce by 18% (4,017 TWh, high scenario) the final electricity demand to 2030, and a 23% in 2050, compared with 2010 base line. By 2018, the goal is to maintain the energy intensity at least equal to that of 2012.
- Electrification Targets - Population with electrical service: 99% in 2018
- Other Targets - In 2017, there are 1,610 MW of nuclear power generation capacity. Additional capacity programmed between 2019 and 2029 is 4,070 MW. CCS is been carried on, but there are not goals established.

A10

- Efficiency Targets - Dutch Energieakkoord: 100 PJ ENERGYSAVINGS BY 2020
- Electrification Targets - 200,000 electric vehicles in 2020

A11

- Efficiency Targets - Focussed on plant performance (EAF >80%)
- Electrification Targets - 90% of SA electrified by 2030. 10% will be non-conventional off grid solution ie micro grids
- Other Targets - Huge potential in SA regarding Underground Coal gasification

- etc. Growing GDP and energy demand requires additional capacity
- A12
- Efficiency Targets - -20 % energy intensity until 2023. Power losses (TSO & DSO) to be reduced to 15% until 2030.
  - Electrification Targets - No clear goals but utilization of 'clean vehicles' will be supported.

A13

- Efficiency Targets - Significant energy efficiency targets and programmes in each individual state. Targets for government buildings. LEED certification for buildings
- Electrification Targets - Incentives and goals vary by state.
- Other Targets - New power plant emission requirements

**8. When considering the above operational issues in your roadmapping approach what additional areas would you consider as a key driver to your roadmap and why?**

- Clearly the aspect of political pressure both from a national as well as a global perspective from a carbon emission view is becoming a key driver to businesses that use coal and fossil fuel to generate electricity.
- Thus with respect to this we have had to look at future technologies that meet the requirements of carbon reduction:

A1

- Decarbonisation Targets - Generation is 99% renewable. Main issue is transportation which is responsible for 42% of GES

A2

- Decarbonisation Targets - Greenhouse gas emissions per unit of GDP: 40-45% below 2005 levels in 2020, 60-65% below 2005 levels in 2030. Achieve the peaking of CO2 emissions around 2030 and to make best efforts to peak early. Launch a national cap-and-trade scheme in 2017. Share of non-fossil fuels in primary energy consumption: 15% by 2020, 20% by 2030. 350GW hydro, 200 GW wind and 100 GW PV, 15% non-fossil fuel energy until 2020.

A3

- Decarbonisation Targets - 40 % GHG emission until 2025-2030. - 30% fossil energy consumption until 2030. 23% share of renewables in primary energy consumption until 2020, 32% until 2030. 40 % share of renewable in electricity generation until 2030

A4

- Decarbonisation Targets - 80 % share of renewables in electricity generation until 2050; 60 % share of renewables in primary energy consumption

A5

- Decarbonisation Targets - Decarbonisation tends to be seen as secondary target – economic growth and security of supply are more important

A6

- Decarbonisation Targets - HKSAR Government is also working to reduce reliance on coal and shifting the fuel mix to more natural gas and nuclear

generation, as well as promoting renewables

A7

- Decarbonisation Targets - 60% share of renewables in primary energy consumptions until 2050; 85-90 % share of renewables in electricity generation until 2050

A8

- Decarbonisation Targets - 22-24 % share of renewables in power generation in 2030. 20-22 % share of nuclear in power generation in 2030. 24 % quasi-self-sufficiency rate, i.e. share of non-fossil energy (renewable and nuclear) in primary energy consumption in 2030

A9

- Decarbonisation Targets - The country assumed the indicative target or aspirational goal of reducing by 2020 thirty percent of emissions compared to baseline; and a fifty percent reduction in emissions by 2050 relative to those issued in 2000. 35% of generation from clean energy in 2024.

A10

- Decarbonisation Targets - -20% CO2 in 2020 compared to the 1990 baseline

A11

- Decarbonisation Targets - 33% share of renewables by 2050. 10% Nuclear by 2050

A12

- Decarbonisation Targets - 30 % share of renewables in electricity generation until 2023. 16 GW solar and 10GW wind until 2030.

A15

- Decarbonisation Targets - 80% greenhouse gas reduction below 1990 levels by 2050. Renewable targets in individual states. New Clean Power Plan with targets for each state

**9. When considering the outcomes in your roadmapping process, what were the critical drivers that influenced your analysis?**

- The most important drivers are asset management and operational efficiencies related to all aspects of our business.
- By improving efficiencies and productivity we can reduce costs. So costs are a key driver
- Regulatory requirements.
- Political pressure in terms of carbon reduction and developing technologies to limit carbon emissions.

**10. What was the resultant impact of the meso/transactional environment on the technology selection process?**

- Meeting regulatory requirements is important.
- Reduce carbon emissions, which means identifying appropriate alternative source of green energy e.g. renewables, nuclear etc.
- Reduce pollution emissions
- Identifying technologies for business improvement processes in terms of sustainable supply to our customers

<ul style="list-style-type: none"> <li>• Cost of development of new technologies</li> </ul>
<p><b>11. How critical was the contextual environment in your analysis, and what macro considerations were taken into account?</b></p>
<ul style="list-style-type: none"> <li>• Contextual environment is becoming an important factor in technology selection in terms of overall environmental sustainability, political acceptance and social requirements.</li> <li>• In addition the economic aspect are critical in terms of organisational sustainability and technology adaptation</li> <li>• In many cases the impact can be political demands, social demands greatly impact the way we undertake our TRM analysis.</li> <li>• Governments continually interfere in state own organisations to a point where it can have huge technology negative impacts on the business and the country.</li> </ul>
<p><b>12. What was the resultant impact of the macro drivers on the technology selection process?</b></p>
<ul style="list-style-type: none"> <li>• A lot more focus on clean technologies focussed on carbon emissions.</li> <li>• This is supported by the fact a big increase in pressure external to the business by way of lobby groups and political pressure.</li> <li>• Customer pressure on more reliable quality of supply and more affordable electricity.</li> <li>• In developing countries a big focus on technologies that are related to affordable supply of rural electrification</li> </ul>
<p><b>13. When considering the operational issues in your TRM process what are the key issues and challenges that you need to build into your roadmap with respect to renewables and why?</b></p>
<ul style="list-style-type: none"> <li>• Big focus on energy transition in the generation area.</li> <li>• Renewables and clean energy production to reduce carbon emissions.</li> <li>• Need to develop a hybrid approach as we cannot just shut down our fossil fuel plants. There would be unintended consequences of this approach and as such need to consider the risks and role out the transition programme accordingly.</li> <li>• There is clearly a cost and funding implication and this needs to be considered in your selection and implementation plan of the TRM</li> <li>• Key operational considerations that we need to consider in our energy transition planning process: <ul style="list-style-type: none"> <li>• Integration of large-scale and centralized renewable generation</li> <li>• Need to assure security, stability and quality of supply to our customers</li> <li>• From an R&amp;D view Improving models to analyse harmonics and resonance issues in wind power plants</li> <li>• Integration of large-scale and centralised renewable generation which means that we have to introduce and consider large-scale and centralized renewable power generation (such as wind power generation, solar generation) and its integration.</li> </ul> </li> </ul>
<p><b>14. How long did your organisation's development roadmapping process take from inception to completion of the final product?</b></p>
<ul style="list-style-type: none"> <li>• It generally takes between 6-12 months to come up with the final report.</li> </ul>





<p>The pressure from both our shareholder and political pressure has resulted in a process that requires that we compress the time of TRM. This results in some case to focus only one the current needs based on political pressure and shareholder requirements.</p> <ul style="list-style-type: none"> <li>• This has resulted in a lot more interference from non technical people, ie shareholder and political interference at times to the detriment of the final output as they are looking for short-term gains.</li> </ul>
<p><b>The strategic role of TRMs</b></p>
<p><b>15. Was the TRM process integrated into other internal strategies, and if so, how were they interrelated?</b></p>
<ul style="list-style-type: none"> <li>• In electricity utilities in most cases the TRM is not integrated into other organisational strategies. In some cases there is a certain amount of integration</li> <li>• The view is that the TRM was developed by the researchers and scientist of the organisation i.e. technocrats and there it must stay. It was seldom integrated fully into the organisations business model however recently this is slowly changing in that issues related to technologies and the approach to energy transition to clean technologies is now becoming a key aspect in our business strategic plan and thus operating model.</li> <li>• The operational side R&amp;D in some organisations would be considered a cost and not a value and thus had a major impact on the funding model of technology in the organisation. R&amp;D was generally seen as a cost not a value.</li> <li>• In R&amp;D institutes the TRM is always integrated into business plans and strategies as it was a key driver in terms of manufacturing and future development</li> </ul>
<p><b>16. In the development of TRMs, where they integrated and developed with external stakeholders, e.g. Customers, regulators etc. and if so, how were they related?</b></p>
<ul style="list-style-type: none"> <li>• No in electricity utility organisations it was done in house with in only in house experts and staff.</li> <li>• We did not bring in external stakeholders.</li> <li>• In the R&amp;D institutes customers were involved in the process. Mainly at the end of process and feedback on the final TRM report.</li> </ul>
<p><b>17. Was there adequate effort and commitment shown in updating the TRM?</b></p>
<ul style="list-style-type: none"> <li>• There is no standard approach to updating the TRM in our organisation. Still undertaken in an unstructured manner, however, we note that this process has started to change due to the importance of appropriate clean technologies in the future.</li> <li>• General practice or process in place in updating. It varies from 2 to 4 years.</li> <li>• As an R&amp;D institute we have a process and continuously look at technologies and would say we tend to update very 2 to 3 years</li> <li>• A key issues related to the updating of the TRM is that in many cases there is a lack of a clear implementation strategy</li> </ul>
<p><b>18. How has your organisation's executive support influenced the success or failure of the TRM process and implementation?</b></p>

<ul style="list-style-type: none"> <li>• Yes executive support the crucial for the success and role of the TRM.</li> <li>• Without executive support funding, rollout and implementation would not happen in the organisation.</li> <li>• Seldom do we apply a robust ROI of the TRM implementation and lack of learning and reflection on the value of the TRM to the organisation.</li> <li>• There is still a lack of disciplined execution process of the TRM and this is due to the fact that there is no clear implementation plan along with the appropriate funding mechanisms.</li> <li>• In some cases executive tend only to use the TRM for their own gain and once final report done and presented executives tend to move on to their next big project. However, there seems to be a change in this behaviour as the pressure for future clean technology for energy transition is becoming a key political key issue both nationally and globally.</li> </ul>
<b>19. How often do you update your TRM?</b>
<ul style="list-style-type: none"> <li>• Every 3 to 5 years. This is dependent on the organisation and the buy in and acceptance of the executives.</li> </ul>
<b>Success factors of TRMs</b>
<b>20. Have you developed critical success factors (CSF) for your TRM implementation?</b>
<ul style="list-style-type: none"> <li>• Generally we have specific CSF for projects however, not r for the entire TRM process in terms of implementation and execution.</li> <li>• As mentioned before this is an area where we lack a robust approach in clearly defining the benefit realisation of the TRM implementation process.</li> <li>• Developing a robust ROI is difficult and seldom done.</li> <li>• There is no check list on how, when we implement the TRM and thus we are extremely weak in discipline, execution and reporting and evaluation of the TRM benefits.</li> <li>• We hardly never with our external customers.</li> <li>• So there is very little focus on developing CSF or KPIs for TRM implementation.</li> </ul>
<b>21. What are the critical success factors (CSF) for the success of TRMs?</b>
<ul style="list-style-type: none"> <li>• As mentioned very little CSFs developed TRM implementation.</li> <li>• As mentioned we plan and develop the TRM report and then fail to develop appropriate CSF and ROI's. As mentioned we do not develop a holistic CSF for the TRM process however, there are CSF for projects within the TRM that is measured.</li> <li>• This is an area we need to improve particularly in having a robust ROI process in order to show both financial, environmental and social benefits.</li> </ul>
<b>22. How do you go about monitoring, evaluating and reporting the success factors?</b>
<ul style="list-style-type: none"> <li>• As mentioned above this area we are extremely weak once we have developed the TRM we feel that the job is done.</li> <li>• We do not monitor the TRM implementation plan but as mentioned above we only track the individual projects.</li> </ul>
<b>23. Do you believe there was value in undertaking the TRM?</b>
<ul style="list-style-type: none"> <li>• Yes we believe it a is major benefit to organisations in undertaking the TRM. It creates value from an efficiency and operational perspective, it give the organisations a view of what technology they need to consider in</li> </ul>

the future as it focuses on operational performance and thus has a huge impact on the financial aspect on the business regarding financial saving and improved performance.

- It also has the potential to develop new innovation products and at the same create engineering and scientific skills and produces products that create value to the business.
- It also always the organisation to utilise the outputs of the TRM in its strategy for the future.

## Appendix 9: Qualitative table of categories, codes and frequencies for the Berlin workshop

	Count	% Codes	Cases	% Cases
 Absorptive Capacity				
◆ Knowledge sharing	6	3,8%	1	100,0%
◆ Multidisciplinary	1	0,6%	1	100,0%
◆ Technology dispersion	2	1,3%	1	100,0%
 Critical elements of al alternate systemic TRM framework				
◆ World view				
◆ Risk analysis	3	1,9%	1	100,0%
◆ Executive buyin	5	3,1%	1	100,0%
◆ Disciplined planning	3	1,9%	1	100,0%
◆ Disciplined execution	1	0,6%	1	100,0%
◆ Benefit realisation	2	1,3%	1	100,0%
◆ Systemic practice	4	2,5%	1	100,0%
◆ Organisational support	2	1,3%	1	100,0%
◆ Customer understanding	18	11,3%	1	100,0%
 Organisational process obstacles				
◆ Operational perspective	14	8,8%	1	100,0%
◆ Lack of ecosystem understanding	5	3,1%	1	100,0%
◆ Shareholder first	1	0,6%	1	100,0%
◆ Short-term focus	4	2,5%	1	100,0%
◆ Conservative	1	0,6%	1	100,0%
◆ Arrogant				
◆ Customer ignorance	1	0,6%	1	100,0%
◆ Sponser influence	2	1,3%	1	100,0%
◆ Organisational ignorance	4	2,5%	1	100,0%
◆ Corporate politics - Lack of support	2	1,3%	1	100,0%
◆ Least cost technology				
◆ Political interference	3	1,9%	1	100,0%
◆ Lack of disciplined execution	4	2,5%	1	100,0%
◆ Lack of appropriate ROI	2	1,3%	1	100,0%
◆ Lack of MRE	7	4,4%	1	100,0%
 Critical constructs				
◆ Ecosystem understanding	9	5,6%	1	100,0%
◆ Organisational resilience	10	6,3%	1	100,0%
◆ Agility	1	0,6%	1	100,0%
◆ Political environment	10	6,3%	1	100,0%
◆ Climate change	17	10,6%	1	100,0%
◆ Environmental impact	13	8,1%	1	100,0%
◆ Systems thinking	3	1,9%	1	100,0%

## Appendix 10: Survey questionnaire feedback

<p><b>What impact has COVID-19 had on the energy system and technology decisions ?</b></p>
<ul style="list-style-type: none"> <li>Although the amount of electricity sold decreased in the first quarter, it is still difficult to determine the impact on our overall business, including the full year of 2020.</li> </ul>
<ul style="list-style-type: none"> <li>There are not big changes in the businesses.</li> </ul>
<ul style="list-style-type: none"> <li>Electricity demand may decline for at least a year. On the other hand, in the medium to long term, demand is expected to increase due to the acceleration of digitalization and the domestic relocation of companies from overseas.</li> </ul>
<ul style="list-style-type: none"> <li>The stagnation of economic and social activities due to the spread of COVID-19 will have a momentous impact on consumer spending in the energy sector around the world, but it is expected that the ratio of electricity will exceed the ratio of oil. Since this is considered to indicate the convenience of electric power and the effectiveness of emergencies, there is a possibility that energy conversion to electricity will proceed further in the future.</li> </ul>
<ul style="list-style-type: none"> <li>COVID-19 will bring short-term and long-term effects to the energy system, and the trend of cooperation in the global energy system will not change. COVID-19 will accelerate the evolution of the global energy pattern. From the overall pattern, the global energy supply exceeds demand will be more obvious in the future. This makes the competition of major energy producing countries more intense and coordination more difficult, the power of discourse and pricing of energy consuming countries will be further enhanced in the future.</li> </ul>
<ul style="list-style-type: none"> <li>World electricity demand reduced by 2.5% in the first quarter of 2020. Covid lockdown measures reduced electricity demand by by approx 20%.</li> <li>Covid lockdowns reduced daily electricity demand by approx 15% in France, India, Italy, Spain, the United Kingdom and the US northwest.</li> <li>It is a bit early to see clearly what will be the consequences on energy system on the long term. However, the IEA and others estimate that the peak of emissions may have been reached in 2019 and there will be a permanent effect on CO<sub>2</sub> emissions.</li> </ul>
<p>In A7,</p> <ul style="list-style-type: none"> <li>Sales of electricity within A7 fell largely due to COVID-19. The pandemic negatively affected electricity sales in most sectors, except for the residential sector where sales increased as people were homebound</li> </ul> <p>In A2,</p> <ul style="list-style-type: none"> <li>Although there are higher generation in renewables because of better resources, wind farms were affected by increased grid curtailments as a result of COVID-19</li> <li>On-grid generation from one of Nuclear Power Stations was below expectations partly due to lower demand due to COVID-19 response measures.</li> <li>Reduced electricity demand as a result of the COVID-19 outbreak exerted pressure on the profit margins of A6 coal-fired generation portfolio. One of our Power Stations has repositioned itself as an integrated energy provider to secure more generation hours as it continues to manage high fuel costs</li> </ul> <p>In A16,</p> <ul style="list-style-type: none"> <li>Apart from technical issues, there are some commercial issues. For example, the share transfer of two solar project may be affected by the COVID-19 situation.</li> </ul>

In A17

- Our performance was affected by lower demand partly resulting from lockdown measures

In A7,

- Expect that the investment into renewable energy increase due to governmental support as economic recovery packages.

- Although the impact of COVID -19 has resulted in a temporary decrease in the energy consumption of society as a whole, once the results of infection prevention measures will be seen, it is considered that energy consumption will return to a certain level along with economic recovery accompanying the movement of people and recovery of physical distribution.

- Energy demand has decreased at our research facilities as a result of less on-site laboratory and office work. To some degree, the demand for and use of electricity has shifted to staff members working from home, but we do not have statistics on that change.
- With much of the world still in a 'reduced mobility' state because of the pandemic, consumption of the fuels and lubricants produced by our clients has decreased significantly. Some commercial clients have reduced R&D funding because of decreased demand and/or economic strains on their organisations. This has been most noticeable in the energy exploration arena and in R&D for improved petroleum and petrochemical processing. R&D budgets have declined severely at most oil and additive manufacturing companies. It may take several years for business to recover to pre-pandemic levels. Government energy programme R&D has been relatively stable. The U.S. Federal government is spending more on alternative/clean energy R&D.

- Electricity demand in commercial and industrial sectors has decreased during COVID-9 which caused lowering electricity production from fossil power plants. Shares of coal and oil on primary energy consumption and electricity generation decreased. This however might be only short-term phenomenon as countries are developing strategies how to tackle COVID-19 crisis. Restored energy demand might be great opportunity for clean technologies to step up after the pandemic.
- One of the most important impact of COVID-19 is influence of clean energy transition. Due to COVID-19 planned investments might decrease and transition to clean energy technologies might slowdown. If fossil fuels costs remain low, it can be also more difficult for clean energy technologies to succeed. On the other hand, the supportive investments planned by European Commission are large and has potential to boost clean energy technologies after COVID-19.

- As there will appear limitation on number/time to call engineers/technicians together, preventive actions would become more important on maintenance and operation of energy system such as on-line monitoring, remote diagnosing of equipment.
- Possible mitigation of economic activity concentration may accelerate energy network to be distributed one.

- With the progress of remote work such as telework, the energy consumption of offices will be suppressed, but the energy consumption of individuals will increase, so it is thought that the energy consumption will be decentralized.

- The current pandemic has significantly reduced the overall electricity demand. Inactivity and temporary closure of business establishments generally caused a drop in commercial and industrial customer consumptions. Whereas, stay-at-home orders caused a shift in the overall increase in residential electricity usage.
- The impact is heavily dependent on the duration of lockdowns and the implementation of strict quarantine measures. Despite this setback, the outlook is that MW demand will recover beginning next year, and we can expect an increase in load-growth related projects to pre-Covid levels in the next two years.
- Moreover, with respect to the 'new normal' and the societal shifts to 'work from home' and online education, a certainty in the near-term is an emphasis on sustaining and improving our existing service reliability, as well as focusing on electrification to provide those in remote and far-flung areas with access to power, which is vital to function in this new environment.

<ul style="list-style-type: none"> <li>• Changed load characteristics that are difficult to predict (some continued working from home may impact commercial load and residential load to some extent). It is not expected that Covid 19 will change the electrification mandates and trends that may dominate load changes.</li> <li>• Control centre design and operation (disinfection practices, changed procedures for operator teams, coordination with remote operators)</li> <li>• Field crew equipment and processes – technologies to support coordination without physical contact such as communications, augmented reality, etc.; sanitization procedures; more automation of functions.</li> <li>• More remote operation of the electric system and associated technologies to support this.</li> <li>• Increased working from home and other factors are increasing the role of the community in energy management as well as many other functions – resiliency, reliability, electrification, decarbonisation.</li> </ul>
<ul style="list-style-type: none"> <li>• In our opinion, COVID-19 will not have a significant mid- to long-term impact on the energy system, other than the expected impacts and developments before the current crisis.</li> </ul>
<ul style="list-style-type: none"> <li>• To prevent the spread of infection, it may not be possible to maintain a system for sufficient maintenance and inspection of electric power equipment at the site.</li> <li>• If the operator is infected, it may be difficult to continue the operation.</li> </ul>
<ul style="list-style-type: none"> <li>• While the demand for electricity is declining, there is a concern that the infection situation will have a further impact on the industrial and the business, so we are watching the infection trend with a serious sense of crisis.</li> <li>• At present, social, and economic activities are gradually resuming, but we recognize that the social and economic situation is in a very difficult situation, such as receiving consultations from customers regarding the timing of payment of electricity and gas.</li> <li>• There is also a movement in society to change the lifestyle itself on the premise of ‘with corona’, and the structure of society and economy, the values and behaviours of customers are changing, and new needs are being met. And social issues will appear. We believe that it is necessary to deliver new values and services that solve such needs and social issues together with energy services.</li> </ul>
<ul style="list-style-type: none"> <li>• The effects of the corona sickness include a decrease in demand, a decrease in fuel prices, and changes in consumer behaviour due to nesting.</li> <li>• Based on national guidelines, we are implementing measures such as establishing a system that enables business continuity even if employees are absent due to infection.</li> </ul>
<p><b>Increased risk awareness/security need</b></p> <p>There could be a</p> <ol style="list-style-type: none"> <li>1. Change in the application of existing technologies to reduce risks</li> <li>2. An increase of demand for security technologies and frugal, crisis-proof technologies (usable with local resources and under difficult conditions)</li> <li>3. Increased expectations of the reliability of services (accompanied by increased willingness to pay)</li> </ol> <p><b>Stronger influence of the state</b></p> <p>Shifting the focus from the markets (failing in the crisis) to state could:</p> <ol style="list-style-type: none"> <li>1. Complicate international projects and make it necessary to build bilateral relations</li> <li>2. Lead to direct or indirect state control of areas considered essential or in distress within the energy system. This point is uncertain though. The energy system did not seem to be under distress during the crisis. Security of supply issues mainly focused on food and products that are used in daily life</li> </ol> <p><b>Regionalization and a strengthened idea of self-sufficiency</b></p> <p>The state-mandated retreat into the domestic environment and the disillusionment caused by the failure of international supply chains could lead to a regionalization of the economy and a stronger self-sufficiency for emotional reasons (neighbourhood) as well as rational motives (security of supply) and a stronger self-sufficiency.</p> <p><b>Accelerated digitization</b></p> <p>The digitalization push could increase the pressure on traditional electricity providers to increasingly digitize the retail business.</p> <p><b>Economic slowdown: impact and countermeasures</b></p> <p>Opposite trends regarding the promotion of energy technologies can be expected here:</p> <ul style="list-style-type: none"> <li>• Due to the now scarcer resources for the promotion of sustainable technologies and to reduce the environmental impact of existing technologies, delays in climate protection and the implementation of the energy transition are to be expected in some parts of the world.</li> <li>• However, climate protection is also used as a stimulus programmeme (in Europe in the form of the New Green Deal) and, for example in Europe, to accelerate the energy transition in conjunction with the now more state-controlled economy. However, economic benefits will be a priority. The increased acceptance of measures which are considered necessary by the state and academia would be supportive.</li> </ul>

- The recent IEA World Energy Outlook provides a good set of forecasts that show likely scenarios for energy and emissions. There is a real opportunity for lost capacity that was taken offline during the global reduction in demand (often from inefficient and dated technology) to be replaced with lower-emissions alternatives. These are usually touted as renewables plus storage, firmed by gas. For these to realise the potential now afforded to them, then we need long-term, flexible, cost effective energy storage (e.g. hydrogen) and commercially viable CO2 storage options. Sectors will also need to be integrated to support the required scale and flexibility.

- The spread of COVID-19 pandemic has been well controlled in A18 compared to rest of the world. According to the TPC's 2020 power sales data, the COVID-19 pandemic only took limited effects on residential, commercial and industrial power usage. The overall year-on-year growth rates of power usage in April and May are -1.0% and -2.1% respectively. In our opinion, the direct negative effect of COVID-19 pandemic on electricity demand is limited. That is, the effects of COVID-19 on energy system may be minor in the short-run. The energy policy is still the key element that determines the shape of our future energy system. However, the lifestyle (both work and leisure) may change in the mid-term or long-term and further cause an indirect effect (of COVID-19 pandemic) on the electricity demand.

- COVID-19 has spread worldwide, threatened human health and impacted global economy. It has become the largest 'black swan' event in recent years, and global energy industry has inevitably been affected.
- COVID-19 reflects the lack of energy emergency management system and cross-regional energy dispatching capacity, and the problem of energy reserves. It leads to the decline of coal consumption of power plants, steel production, refining capacity and the cancellation of most flights. However, governments' forthcoming incentives may offset its impact on energy demand and carbon emissions. At the same time, COVID-19 also promotes the transformation of social production and life style, and gives rise to the digital transformation of energy industry. For example, it will contribute to the development of energy block-chain technology and unattended digital energy enterprises.

- I think this is a good opportunity to transform the energy structure amid major changes in working styles and values.

- The effects of COVID D-19 is hitting the societies hard, but we also see an increased focus on stimulating green solutions and sustainable development as a countermeasure from governments to stimulate the economy.

**What technology development (roadmapping ) items need to be planned for the future?**

- As the amount of renewable energy becomes bigger and bigger, ancillary technologies are needed.
- Also, the position of thermal power should be reviewed because the fluctuations of the renewable energies are compensated mainly by the electricity of thermal power.

- We believe that it is necessary to work on technologies such as promotion of electrification and renewable energy while taking into account social conditions such as acceleration of digitalization and heightened resilience awareness due to the influence of COVID-19.

- The basic measure is to 'reduce contact between people', and it is thought that remote work and remote inspection by robotics will be promoted. It has a high affinity with Dx conversion, and it is necessary to develop data analysis technology collected by sensing and optimization of communication/transmission means. For this reason, there is a need for technology that digitizes information that comes out of electric power equipment in every part.

- COVID-19 has accelerated the process of global low-carbon transformation. A2 is ready to take new energy investment as an important way of economic recovery. Traditional fossil energy investment will be greatly impacted, and new energy investment will recover faster and grow against the market. Therefore, in the post epidemic era, it should pay more attention to and accelerate investment and cooperation in new energy electrification and other fields.

<ul style="list-style-type: none"> <li>It is necessary to promote technological development related to telework at home or local community but also ways to work together physically in a workspace. There is a risk that R&amp;D and technological development will be reduced as a result of Covid 19. Probably public budgets for R&amp;D and innovation will be less affected than the corporate ones since lots of companies will try to focus on recovering from the crisis rather than maintaining or increasing their R&amp;D and innovation budgets.</li> </ul>
<ul style="list-style-type: none"> <li>As a countermeasure against the infection of the new coronavirus (COVID-19), we are taking measures such as telework and video conference ahead of urgent business trips.</li> <li>We believe that telework will further expand in the future as one of the measures for ‘new work style’, not limited to measures against the new coronavirus (COVID-19) infection.</li> <li>However, we are in a position to introduce and operate the developed technology, and we have no plans to promote technology development related to telework.</li> </ul>
<p>In A7,</p> <ul style="list-style-type: none"> <li>We will continue to focus on ensuring the reliability of customers as they deal with the issues arising from COVID-19. A7 is committed to ongoing innovation and enhancements to further strengthen its operational resilience at a time of uncertainty over the long-term impact of the global pandemic.</li> <li>We will continue efforts to minimize COVID-19-related delays in capital projects supporting the decarbonization of Hong Kong, which remains the Group’s core market.</li> </ul> <p>In A2,</p> <ul style="list-style-type: none"> <li>We will continue to focus on maintaining the integrity s in Mainland A2 to support the national recovery from COVID-19.</li> <li>We will also explore investment opportunities in smart energy businesses to diversify its operations and contribute to the ongoing energy transition, with a particular focus in the Greater Bay Area.</li> </ul> <p>In A17,</p> <ul style="list-style-type: none"> <li>We will continue to face challenging market conditions as the economy emerges from COVID-19 restrictions. The level of customer hardship, the speed of demand recovery, the intensity of retail competition and the longer-term outlook for price regulation will all have significant impact on margins for the Customer business. In the meantime, the continuing decline of forward prices in the wholesale market will put pressure on the margins in the Energy business.</li> <li>In response we will continue to focus on extending appropriate support to customers as well as safeguarding the wellbeing of its employees and maintaining operational and supply reliability. For example, to maintain supply reliability, two major maintenance outages are being undertaken, and will take place in 2021.</li> <li>Looking further ahead Energy A17 would like to aim for carbon neutral by 2050 and is committed to a national system which provides cleaner, more reliable, and affordable energy, underpinned by renewable generation.</li> <li>The potential expansion of new gas-fired generation options is being assessed to support the development of a decarbonized and modern energy system for Australia</li> </ul>
<ul style="list-style-type: none"> <li>The countermeasures to accept more renewable energy become more important such as energy storage system.</li> </ul>
<ul style="list-style-type: none"> <li>The shift to a lifestyle that utilizes the Web will accelerate even further, and it will be enhanced by remote communication and virtual reality. It is necessary to expand the hardware and software aspects that support them.</li> </ul>
<ul style="list-style-type: none"> <li>We do not see a need for or plan to change our own technology energy sources. We have no easy means for making a change because electricity is supplied to our facilities by a single utility. That utility uses diverse sources and continues to increase the mix of ‘green’ energy; this has been ongoing and is expected to continue regardless of COVID-19 impacts.</li> <li>Some clients appear to be increasing R&amp;D in alternative/clean energy, energy storage technologies, and other areas. For example, there is a continued push toward vehicle electrification. This may not be a direct result of COVID-19,</li> </ul>

<p>though some politicians and clean-energy advocates call for using the pandemic as an opportunity to rebuild/recover to a more green and sustainable state. Regardless of motivation, it continues to be a focus of the automotive industry.</p> <ul style="list-style-type: none"> <li>• Barriers to widespread electrification include the need for advanced battery technology (lower cost, reduced dependence on rare earth metals, higher capacity), insufficient charging infrastructure, and low consumer demand/acceptance. Until these barriers are overcome, internal combustion engines (ICE) in both conventional and hybrid applications will continue to dominate the market.</li> </ul>
<ul style="list-style-type: none"> <li>• During pandemic it is more than ever obvious that grid robustness and stability is a key aspect to tackle and overcome the crisis. Energy storage technologies such as batteries, hydrogen technologies, pumped hydro energy storage can support this aspect and can help maintain energy supply security. CCGT power plant are also becoming more important since high shares of renewables are planned to take a part in energy transition.</li> <li>• COVID-19 might speed up digitalization of processes and communication between people. Technologies such as digital twins and documentation and asset management might become more important.</li> </ul>
<ul style="list-style-type: none"> <li>• On-line monitoring, (AI) diagnosing system, cyber security for man-power saving.</li> <li>• EMS, batteries, (Small/Medium) electronic inertia source for distributed energy network</li> </ul>
<ul style="list-style-type: none"> <li>• With the progress of remote work such as telework, it will be necessary to promote technological development related to ICT such as web conferencing and remote monitoring.</li> </ul>
<ul style="list-style-type: none"> <li>• Continuation of all innovative and technology solutions that were already started pre-pandemic time. With the Covid-19 pandemic, these technology and innovation initiatives, particularly Cybersecurity measures, prove to be more essential as we spend more time online (e.g., virtual meetings, remote-working set-up, online payment/transactions, etc.) due to physical distancing and other health protocols. The business disruption caused by the pandemic has created several cybersecurity risks that need to be addressed by the utilities.</li> </ul>
<ul style="list-style-type: none"> <li>• Technologies to support remote operation of the grid (secure communications and identity verification, management systems that support remote operation)</li> <li>• Increased automation on the grid in general to minimize requirements for crews to perform service.</li> <li>• Augmented reality to support remote operation and functions.</li> <li>• Asset management strategies that involve increased data from sensors, condition assessment, data analytics and maintenance on an as needed basis.</li> <li>• Disinfection technologies for offices and control centres.</li> <li>• Home office technologies – cyber security, video conferencing, augmented reality, increased broadband deployment</li> </ul>
<ul style="list-style-type: none"> <li>• If at all, the automatization of operations and remote work may increase. However, this development was started and ongoing already before the current crisis.</li> </ul>
<ul style="list-style-type: none"> <li>• Technology development related to remote patrol and inspection of electric power equipment utilizing IoT technology and 5G technology</li> <li>• Technology development aiming at automatic operation or semi-automatic operation of electric power equipment</li> </ul>
<ul style="list-style-type: none"> <li>• Technology to continue business while working to prevent infection as an infrastructure company, content that supports telecommuting and business.</li> </ul>
<ul style="list-style-type: none"> <li>• Since it is unclear to expect the effects of the corona sickness in the future, it is difficult to state a clear policy, but we will work on technological development as necessary.</li> </ul>
<p>Potential technological impacts in the energy industry:</p> <ul style="list-style-type: none"> <li>• Boost of existing solutions for security of supply in terms of electricity and heat (e.g. uninterruptible power supply)</li> <li>• Promoting existing and developing new energy technologies with the possibility of strategic stockpiling or diversification of sources (e.g. LNG, in some countries nuclear energy or prolonged use of coal, later also green fuels)</li> <li>• Development of new possibilities for storage/storage of energy sources (e.g. caving storage)</li> <li>• Developing long-term backup capabilities/flexibility options</li> <li>• Improving network security</li> </ul>

<ul style="list-style-type: none"> <li>• Increased expectations of the reliability of end-user solutions such as quarter or industrial solutions for optimal control of energy flows ('Energy Manager')</li> <li>• Development of hygiene solutions and health protection concepts for the sharing economy and public transport</li> <li>• Development of technologies that are needed from a scientific point of view in the long term to achieve policy objectives (e.g. hydrogen economy)</li> <li>• Focus of network development on regional interconnectivity - no cross-border 'supergrids'</li> <li>• Bilateral country partnerships for the development and use of renewable power generation/fuels - less cross-cutting international approaches</li> <li>• Promoting quarter solutions</li> <li>• Strengthen the role of the distribution network</li> <li>• create new opportunities for the delivery/billing of tenant/neighbourhood electricity</li> <li>• boost demand for electricity or even energy self-sufficiency systems</li> <li>• increase the acceptance of domestic renewable power generation, especially onshore wind</li> <li>• demand for domestic energy sources. In the case of renewable energy sources, for example, increased production of biogenous energy sources or domestic hydrogen production would be possible</li> <li>• Promote technologies to improve EE integration (e.g. demand side response, battery storage, optimized power control, possibly DC networks)</li> <li>• in the event of reindustrialisation, the energy control of complex domestic industrial enterprises (e.g. micro factories) is required</li> <li>• promote domestic production of energy technologies (e.g. fuel cells)</li> </ul>
<ul style="list-style-type: none"> <li>• For gas to play a firming role in emissions reduction it cannot be used in inefficient open-cycle systems. While cheap and flexible, these are not efficient, and are not consistent with the goal of emissions reduction.</li> <li>• Energy storage options need to be larger and longer-term than batteries to support RE unavailability for days. Bioenergy deployment is also needed as a renewable, despatchable generator.</li> </ul>
<ul style="list-style-type: none"> <li>• Although the COVID-19 pandemic doesn't cause a huge impact on electricity demand and lifestyle in A18 in the short-run, the concept of decentralization and digitalization is getting more and more attention after this incident. With the help of ICT (information &amp; communication technology) and related software (for telework, data analysis etc.), the implement of the concept becomes possible and realistic. We think that IC and data analysis (data mining, AI) are the necessary technology development items.</li> </ul>
<ul style="list-style-type: none"> <li>• We should promote distributed intelligent micro-grid applications. COVID-19 shows the lack of national capacity for energy emergency reserves and cross-regional power dispatch. It is necessary to strengthen energy emergency reserves and construct a multi-level and multi-energy reserve system through countries, regions and enterprises, to effectively suppress the fluctuation of electricity market in emergencies. The construction and application of distributed intelligent micro-grid need the further development of related energy storage and regulation technology, and the support of relevant national policies.</li> <li>• We should further develop energy efficiency and integrated energy control technology for electrical equipment. Because of delayed work resumption, electricity consumption in industry and commerce has declined during COVID-19, Meanwhile, there has been a substantial increases in electricity consumption by residential users. Owing to COVID-19 on economic development, it is important to consider more attention to energy consumption of residents and buildings. Research and application of energy efficiency and integrated energy regulation technology will realize user-side resource intelligent sensing. Through active response and friendly control, users will be promoted to reduce costs and increase efficiency.</li> <li>• We should also advance the remote control of protection relays, such as the remote monitoring of the state of the relays and remote setting changing with an App in a normal mobile phone, under sufficient safety guard.</li> </ul>
<ul style="list-style-type: none"> <li>• In preparation for COVID-xx, it is necessary to establish in advance information on infection status, prompt development of vaccines and silver bullets, harmony with remote life, infection prevention methods, etc.</li> </ul>
<ul style="list-style-type: none"> <li>• Improved reliability and availability in the residential market for teleworking</li> <li>• Assumed automation of industrial sector and increased reliability</li> <li>• Use of remote working technologies such as Augmented reality to reduce the number of staff working at site</li> <li>• Increased focus on separation of critical teams such as the control centre operators.</li> </ul>

- More focus on digital communication solutions and sustainable energy solutions

**What policy interventions are you considering for coping with social demands in the field of future technology adaptation and power generation?**

- In the power generation, along with the restart of the Nuclear Power Station, we are proceeding with the expansion of the introduction of renewable energy power sources and the construction of the Power Station, which is balanced from the perspectives of economic efficiency, reduction of CO<sub>2</sub> emissions, and securing of stable supply. We will continue to configure the power supply with a good balance.

- As it is difficult to operate the nuclear power in A9, it is needed to establish the new energy plan by the government. A9 cannot exist without nuclear and thermal power.

- Through the development of offshore wind power generation, participation in overseas hydroelectric power generation business, restart of nuclear power plants after establishing the world's highest safety level, and improvement of efficiency of existing thermal power, we aim for decarbonisation. Thus we are working on the expansion of an offshore wind power generation system that is suitable for the A9 environment and is cheaper than other power sources.

- With nuclear power generation and renewable energy, which are non-fossil fuel power sources, as the two wheels, we will continue the development of renewable energy power sources along with the stable operation of nuclear power generation. It will also improve the thermal efficiency of conventional thermal power, which is a fossil fuel power source, and lead to CO<sub>2</sub> reduction.

- Evolution of grid codes and electricity markets, the growing sensibility of the public about the environmental impact and the risks generated by operating hydroelectric power plant, and the increasing demand for comprehensive utilization of water resources, lead to the prominent difficulty of generation dispatch decision-making.
- Giant unit/plant capacity and development of cascade hydroelectric power plants require integrated operation & management. The latest technologies such as cloud computing, artificial intelligence, big data, Internet of Things, Mobile Terminal, and virtual reality will trigger a revolution of automation system for hydroelectric power plants.
- Hydroelectric power plants and remote-control centres are in need of advanced technologies to strengthen information sharing and coordination among equipment and applications. To cope with the challenges of operation & maintenance, dispatch, management and so on, innovation involving multiple elements in regards of system architecture, information model, integrated standards, software structures, business procedure, applications, optimized models, etc., should be carried out, thus to build a 'Smart Hydroelectric Power Plant'.

- Decarbonisation is an urgent issue and an international agreement. Gas and electricity grids should be move to renewables energies to ensure decarbonized as possible. We should continue to invest in gas networks, adapting to future requirements in terms of green gas.
- We need to work on the combination of advanced and made-to-measure technologies (energy efficiency offers and co-generation). Gas power plants are necessary in addition to renewables energies.

- Coal is widespread and abundant all over the world, and its supply is stable. For A9, which has experienced two oil crises, coal is an important resource for achieving a balanced energy composition from the perspective of 'energy security'. In order to solve the world's energy access improvement problem and climate change problem at the same time, and to realize a sustainable, diverse and inclusive society that the SDGs call 'no one is left behind', it is necessary to ensure that people have access to affordable, reliable, sustainable, and modern energies. In addition, it is vital to recognize that it is important to reduce CO<sub>2</sub> emissions not only in coal but also in whole energy use. In the world, it is necessary to support the economic growth of emerging countries and other countries with growing energy demand with cheap electricity supply.

We are addressing on the following technological developments with the aim of reducing CO2 emissions (zero emissions).

- (1) Integrated Coal Gasification Combined Cycle (IGCC)
- (2) Integrated Coal Gasification Fuel Cell (IGFC)
- (3) IGCC/IGFC with CO2 separation/capture
- (4) CCS/CCUS
- (5) Co-firing biomass with coal

In terms of decarbonisation and intermittency, different speed of action in different markets  
Relevance and pace different

Aligning with the policies in our markets

- share the responsibility to alleviate climate impacts;
- moving away from carbon-emitting production;
- and focus on business prospects that deliver worth by limiting carbon

In line with decarbonisation strategy, A7 plans to take future actions:

- Reduce investments in coal-fired power production
- Identify opportunities to phase out of coal from our generation portfolio;

Increase renewable energy production and focus on decentralised smart energy solutions.

- The position of nuclear power should be clarified if unclear could be considered as measure for decarbonisation.

- To achieve a low-carbon, decarbonized society, there will be an increase in the use of renewable energy and an accelerated movement toward a hydrogen society. Even in this transition, a clean power generation system that maintains 3E + S (Environment, Economic efficiency, Energy security and Safety) will be required. Examples include high-efficiency GTCC, ammonia co-firing, biomass co-firing, CCS + CCUS and hydrogen gas turbines.

- U.S. national policies aside, climate change mitigation is increasingly a strong social demand. In response to this social demand, as well as economic factors, industry continues to move away from coal- and oil-fired electrical plants. Therefore, efforts should be made toward decarbonisation by decreasing emissions and improving efficiency of existing and new energy infrastructure. Replacement of carbon-emitting technologies with renewables (PV and wind) will require development of sustainable low-cost, long-term grid-scale energy storage technologies.
- Because coal continues to play a major role in global energy production and internal combustion engines are the international norm, our organisation is conducting R&D to address carbon emissions in several areas. These include (i) vehicle research, including emissions reduction, hybrid vehicle technology, and electric vehicle technology (including battery performance and safety); carbon capture and conversion associated with making Portland cement and similar products, electrical power production, and industrial processing; efficiency of power production such as the use of super-critical carbon dioxide systems; and storage technologies to facilitate expansion of solar and wind energy, particularly solar-battery and wind-pumped hydro storage systems.
- We also conduct R&D related to nuclear power generation; transportation, storage, and disposal of radioactive wastes; and associated environmental impacts and implications.

- Conventional power plants will still play an important role in near future since they will be mitigating threats regarding power generation intermittency. Until the energy storage will be commercially developed and able to cover seasonal energy demands, conventional power plants including CCGT technology will remain useful tool how stabilize generation from renewable sources. Therefore, increasing energy efficiency of these facilities can help lowering global emissions. In area of centralised heating and cogeneration shift from coal power plants to natural gas is viable step for lowering emissions for heat supply. CCGT is also promising with respect to decarbonised power sector via the conversion of existing natural gas grids to hydrogen enriched up to full content.
- Decarbonisation is a modern issue which help society to move forward to clean, sustainable and secure power generation. Multi-layer support of new technologies and renewable sources is important if we want to achieve carbon neutral society.

<ul style="list-style-type: none"> <li>• Electrification of certain sectors where fossil fuels replacement is difficult might help decarbonisation process, as long as power generation is gradually decarbonized. Therefore, power generation decarbonisation and solutions regarding grid stability and energy storage are the most important first steps.</li> </ul>
<ul style="list-style-type: none"> <li>• Gas-fired power generation and nuclear power generation are expected to contribute to societal needs, such as the advancement of renewable energy, decarbonisation, and decentralization of power sources, mainly for baseload and peak power applications for grid stabilization.</li> <li>• In terms of Intermittency, we believe it is important to expand the menu of IoT solution services to improve the efficiency and reliability of power plants.</li> </ul>
<ul style="list-style-type: none"> <li>• The development of renewable energy is important for decarbonisation, but since solar power and wind power generation are greatly affected by the weather, thermal power generation also plays a major role in adjustment. In order to achieve both environment and economy, it is necessary to utilize the characteristics of each power source such as renewable energy, nuclear power generation, and thermal power generation, and to have a well-balanced power source composition based on regional characteristics.</li> </ul>
<ul style="list-style-type: none"> <li>• Decarbonisation is a priority everywhere. Combined with continued declining costs of wind and solar, it means that almost all new generation is renewable.</li> <li>• Local community energy management is an increasing priority resulting in concepts like community solar and storage becoming an increasing priority.</li> <li>• Decreasing costs of energy storage is making it a legitimate peaking resource, especially in California at this time. Distributed storage continues to grow with the potential to be a demand management and flexibility resource as well as supporting local resiliency (increasingly important)</li> <li>• Flexibility is critical – markets and TSOs must understand where flexibility requirements will come from as renewable penetration increases (see recent rolling blackouts in California as an example).</li> </ul>
<ul style="list-style-type: none"> <li>• Decarbonisation is an urgent issue and a mostly international agreement. Power generation that emits carbon should be phased down as soon as possible within a reasonable and manageable period. Security of supply both to industrial and private consumers should be considered and not be put at risk at any time during this transition period. This may be done by various different ways, depending on each country and respective consumer landscape and policies</li> </ul>
<ul style="list-style-type: none"> <li>• Integrated coal Gasification Fuel cell Combined Cycle (IGFC), which is the ultimate high-efficiency coal-fired power generation, as a technology that contributes to ‘high efficiency’ and ‘low carbonization’ in order to utilize coal-fired power with excellent supply stability and economy in the future. We are implementing a project aimed at realizing innovative low-carbon coal-fired power generation that combines IGFC and CO<sub>2</sub> separation and capture.</li> </ul>
<p>Low carbon power supply</p> <ul style="list-style-type: none"> <li>• Research to increase the introduction of renewable energy power sources</li> <li>• Improved safety and economy for utilizing nuclear power generation, which is a zero-emission power source</li> <li>• Higher efficiency and zero emission of thermal power generation</li> </ul>
<ul style="list-style-type: none"> <li>• Policies have been employed by Government to promote sustainable sources of energy and to support the development of renewable energy in the country, which started in 2008 with the enactment of Republic Act No. 9513. This provides a variety of support schemes and mechanisms, such as Feed-In Tariff system and Net Metering to increase the deployment of utility-scale and small-scale RE technologies/system across all sectors.</li> <li>• In compliance with the Renewable Portfolio Standards (RPS) under the RE Act and as part of the Company’ sustainability agenda, Meralco has already considered Renewable Energy sources as part of its supply portfolio as can be seen in its annual Power Supply Procurement Plan (PSPP). For a distribution utility’s point-of-view, Meralco secures affordable energy resources based on a least-cost manner for its customers through a Competitive Selection Process (CSP) to award and secure power supply agreements.</li> </ul>
<ul style="list-style-type: none"> <li>• Recognizing that decarbonisation is an important social requirement, we are proceeding with technological studies such as improving the efficiency of thermal power plants as specific measures, and CCUS and hydrogen are expected to be effective technologies for future decarbonisation. We are collecting information on related technologies and studying their utilization.</li> </ul>

<ul style="list-style-type: none"> <li>• However, in order to implement these new technologies, there are problems such as the need for further cost reduction.</li> </ul>
<p>At present, following items are key technologies in the field of thermal power.</p> <ul style="list-style-type: none"> <li>- Zero Emission Thermal Power</li> <li>- Capability for wide load range (Corresponding to load fluctuation for renewable energy, Expansion of output range)</li> <li>- HELE (High Efficiency Low Emission)</li> <li>- In the near future, it seems that the power share of Renewable Energy, especially offshore wind power will increase in Japan. Utilization of low carbon resource and carbon recycle are also important.</li> </ul>
<ul style="list-style-type: none"> <li>• A6 The future policy of the corporation is still under consideration. However, it is clear that there will be no emphasis on power generation, but a strong focus on distribution grids and customer solutions (mainly retail business), both for electricity and gas.</li> </ul>
<ul style="list-style-type: none"> <li>• For the energy transition to be effective and timely, we need to find a way of bringing the existing, large energy companies on the journey (rather than finding ways of excluding them). These corporations have the balance sheets to support the deployment of relatively-risky technologies and to operate at a scale that supports real impact. By focusing on a goal of decarbonisation, rather than ‘renewable’ or ‘fossil’ we are more likely to have meaningful outcomes in realistic timeframes.</li> </ul>
<ul style="list-style-type: none"> <li>• Decarbonisation is an urgent issue and an international agreement. Power generation that emits carbon should be stopped immediately. Coal should not be accepted except by CCUS.</li> <li>• Thermal power generation such as coal also plays a large role in Taiwan because the storage and transportation of LNG is not as easy as coal. Since the CCPPs can’t replace the coal power plants, the TPC needs to develop CCUS technology to reduce carbon emission.</li> <li>• However, CCUS is facing the challenge from local stakeholder in Taiwan. Most of people concern about the safety issues related to earthquake, and some people concern about the issues of CO2 leakage. To solve the problem, TPC will focus on the research of the related issues that people care about.</li> <li>• Decarbonisation is our company’s goal and society’s expectation. We are gradually moving towards the goal of decarbonisation and gradually increasing the renewable energy capacity. TPC also constructs flexibility combined-cycle power plants to response to the intermittent renewable energy. The low-pollution advanced USC unit is used as the base-load unit and serves as the blueprint for Taiwan’s power planning.</li> </ul>
<ul style="list-style-type: none"> <li>• It is necessary to reduce carbon while ensuring a stable supply of electricity. The method varies greatly from country to country, and it is too irresponsible to impose what one country is doing, as another country cannot do the same thing.</li> <li>• The stable supply of electricity must be evaluated not only in terms of quantity of supply but also in terms of geopolitical stability, supply fluctuations, system stability, and price.</li> </ul>
<ul style="list-style-type: none"> <li>• Increasing diversity of the generation technologies with increased focus on environmentally sustainable technologies such as Solar, Wind, Nuclear</li> <li>• Increased focus on flexibility of the various base load generation technologies</li> <li>• Better energy planning for resource adequacy</li> <li>• Separation of the vertically integrated energy industry.</li> </ul>
<ul style="list-style-type: none"> <li>• Climate friendly solutions are increasing momentum, e.g. offshore wind, CCUS, Blue hydrogen with CCS, increased electrification (based on renewable sources)</li> </ul>
<p><b>What is your future technological implementation approach?</b></p>
<p><b>PV</b></p>
<p>Ancillary services</p>
<p>Output prediction, panel deterioration diagnosis, utilization as an emergency power source in case of a disaster</p>
<p>Solar power short-time prediction system</p>
<p>Agri-PV, solar field</p>
<p>Actively involved in solar-battery storage research, including a joint demonstration project with the local electrical utility.</p>
<p>Land occupation, efficiency, output forecast</p>
<p>Frequency, system stability</p>

Integration of smart inverters, availability of short and long term storage for intermittency and variability, local PV management and integration for distribution systems.
For A6, the utilization of PV has a very high priority, however, we will not do any technology R&D ourselves, but piloting new value pools of PV.
High conversion efficiency solar cell
Output prediction, effect on grid
Efficiency gains via new materials (e.g. Perovskites)
advanced organic solar cells, output forecast, flicker
Large scale PV farms, IPPs, short term and long-term forecasting, inertia, reactive power
<b>Wind power</b>
Ancillary services
Floating offshore wind turbine
Onshore and offshore wind, floating wind turbine
Offshore wind power
Conducting R&D on use of pumped storage hydro (PSH) to facilitate wider use of this intermittent power source.
Evaluation of suitable places to increase installed power, floating wind turbine, small wind turbines
Wind Firm O&M systems to improve maintainability./Localization (Domestic production) of wind turbine key products.
Frequency, system stability
Controls to provide flexibility from wind turbines, Floating offshore wind technologies, integrating offshore wind with the grid, development of hydrogen infrastructure for long term storage and use of excess generation.
For A6, the utilization of wind power has a very high priority, however, we will not do any direct technology R&D ourselves, but piloting new value pools and technologies, e.g. high-altitude wind power and operation improvements.
Floating offshore wind technology
Offshore wind power, maintenance/inspection, output forecast
Offshore wind power, environmental effect assessment
floating wind turbine, high-altitude wind, output forecast, Flow field simulation
On shore wind farms, power quality, forecasting
Large scale Off-shore wind technology development and implementation
<b>Hydropower</b>
Frequency control
Upgrading of dam operation (flow rate forecast using big data, etc.)
Smart Hydropower
Optimize the assets' availability, Optimize O&M costs, Maximizing generation at peak price, Optimize the assets' availability and response time (ancillaries...)
Strengthen resilience of hydropower station
There are not too many technical issues.
Conducting R&D on use of pumped storage hydro (PSH) to facilitate wider use of this intermittent power source. We conduct environment assessment for various sources of energy and other projects but have not yet done an environmental impact statement (EIS) for a major hydropower project.
Frequency control and grid stabilization, analysing pumped energy storage possibilities in present hydro power plants
Advanced maintenance technology
Resource in many locations that provides the flexibility for broader renewables integration, controls development for integration of renewables.
Advanced maintenance (AI, etc.)
Maintenance and inspection
Remote monitoring control, drone
frequency control, operation plan, AI control, environmental protection, output forecast
Dam infrastructure
<b>Geothermal</b>
Our organisation wants to become a world leader in <b>geothermal</b> energy by 2030, with a <b>strategy</b> focused on electricity generation, heating and cooling networks, as well as decentralised heat and cold generation. A key success factor in this <b>strategy</b> is Storengy's know-how and operational experience in subsurface activities
Geophysical monitoring
Efficiency improvement
Efficiency improvement.
Limited availability. Great resource where it is available, continued improvement in characterizing geothermal potential and technologies to operate with efficiency and flexibility.
R&D in implementation of geothermal heat in the power sector.
exploration technology, efficiency improvement, environmental protection
<b>Ocean energy</b>
Just technology watch

Tide power generation
Economics of most ocean energy technologies unlikely to become attractive compared to offshore wind. Significant development needed to reduce costs and minimize impacts.
Wave power generation
Offshore systems for hydrogen production and integration into other offshore industries (such as aquaculture).
Tracking technology developments
<b>LNG</b>
High efficiency, O & M cost reduction
Energy-saving CO <sub>2</sub> separation and recovery technology
For maritime transport, small scale LNG
The project is one of the key parts of our support to the A7 Government's target of growing the use of gas to approx 50% of the total fuel mix for electricity generation at 2020, and of our strategic shift to gas as a lower-carbon alternative to coal, driven by our Climate Vision 2050.
efficiency improvement
We conduct fire, explosion, and risk studies related to rail transport of LNG and other flammable fuels.
Environmental protection
Natural gas will continue to be critical flexibility and reliability resource for decades. Flexible operation, minimizing fuel, and designs to allow hydrogen operation as the economics improve.
A6 has a pure trading focus regarding LNG for the time being.
Light LNG
Efficiency improvement, blade material, AHAT (Advanced Humid Air Turbine), Fast start-up gas turbine utilisation and/or storage; emissions from extraction and production.
efficiency improvement, environmental protection, cold energy
No local resource – available in neighbouring countries
<b>Coal</b>
O & M cost reduction
Advanced operation of coal-fired power generation utilising AI technology/CO <sub>2</sub> separation and recovery technology
IGCC, IGFC, CCS/CCUS, SOFC
In our Climate Vision 2050 is that no additional coal-fired power generation will be added to our portfolio. We would like phase out our coal-based plants by 2050 at the latest.
IGCC, CCUS
We conduct R&D in carbon capture and conversion, as well as certain areas of clean-coal technology.
Improved efficiency through supercritical CO <sub>2</sub> and flameless pressurized oxy-combustion.
Operation availability and reliability increase
Environmental protection
Biomass mixed new fuel
Without CCUS, coal will continue to decline as a generation resource. Even with CCUS, gas is likely to take precedence.
A6 is phasing out its coal plants until 2038.
IGFC
Cost reduction (A-USC, CCUS), maintenance/inspection
Utilization of coal ash, operational improvement, mixed Burning
IGCC (Integrated coal Gasification Combined Cycle), environmental protection, carbon recycle
Gasification pathways for hydrogen production.
CCUS, environmental protection
Current build programme started about a decade ago
<b>Biomass</b>
Biofuel with microalgae
Retrofit of unit, biomass collection, biomass evaluation, environmental protection
Co-firing with coal
mixed burning
Peletization, different mixtures of solid biomass
Biomass mixed new fuel
Biomass still has a role – can be part of local energy systems, can be source of flexibility
Topic is implemented in the Netherlands due to national subsidy scheme. Large scale coal PPs are transferred to biomass by a phased approach (co-firing 50% - 80% to 100% biomass). R&D is done on different biomass feedstocks and plant/process adjustments.
Torrefaction, Grinding technology, Blended combustion, Improvement of boiler efficiency
Energy recovery from waste, waste as feedstock for industrial processes, chemical recycling of plastics. Alternative pathways for hydrogen production.
<b>Nuclear</b>

<ul style="list-style-type: none"> <li>• Output Control, SMR, Radioactive waste disposal</li> </ul>
<ul style="list-style-type: none"> <li>• Research that contributes to nuclear safety, offshore nuclear power, and next-generation nuclear reactors</li> </ul>
<ul style="list-style-type: none"> <li>• Advanced MOX fuel, improvement of container heat removal, Evaluation of geology and earth-quake, etc.</li> </ul>
<ul style="list-style-type: none"> <li>• We conduct R&amp;D related to nuclear power generation; transportation, storage, and disposal of radioactive wastes; and associated environmental impacts and implications. We have world-class non-destructive evaluation and testing technologies for inspecting nuclear power plants to assure safety and increase public confidence. We conduct hazard and risk assessments for various operating and planned nuclear fuel-cycle facilities.</li> </ul>
<ul style="list-style-type: none"> <li>• Nuclear is part of the decarbonisation solution in many systems. The main problem is the cost of new nuclear power plants. Research focused on SMR that can be deployed safely and at a reasonable cost is very appropriate.</li> </ul>
<b>What are some of the key risks regarding future technology application and potential solutions?</b>
<b>PV</b>
Technology: PV  (1) Reason: Solar energy supply is plagued by intermittency. It also occupies large land mass relative to power generated. (2) Technical items: Needs to be coupled to safe cost-effective energy storage systems such as batteries, compressed air energy storage (CAES), or pumped hydro storage (PHS). In addition, bifacial PV technologies have the potential to significantly reduce the amount of land per kW generated. (3) Issues to be solved: Battery storage safety, efficiency, and longevity. High efficiency turbines to recover energy from CAES. Reduced construction timelines, cost, and environmental acceptability of PSH systems.
Technology: PV  (1) Reason: PV extension is a crucial for increasing shares of RE and clean energy transition. (2) Technical items: Intermittency solution (3) Issues to be solved: PV power generation coupled with energy storage creating complex and robust system with stable electricity supply or supply on demand; Round trip efficiency of electrical energy storage and implementation of large scale technologies.
Technology: Emerging Solar  (1) Reason: we want to become carbon neutral producer of electricity (2) Technical items: stability overview emerging technologies (3) Issues to be solved: integrating emerging technologies with standard silicon PV
<b>Wind power</b>
Technology: Wind Power  (1) Reason: There is a great social demand for decarbonisation, and we believe that floating offshore wind power has the largest potential power generation capacity for renewable energy in consideration of location conditions. (2) Technical items: Floating offshore wind turbine (3) Issues to be solved: We must establish offshore wind power plant design, construction, and maintenance operation technology that can withstand the harsh environment of Japan and have few landing-type applications. It needs to be realized low cost compared to other power generation methods.
Technology: Off-shore Wind  (1) Reason: we want to become carbon neutral producer of electricity; Floating wind is no longer confined to R&D and is ready for large-scale deployment. It can benefit from the cost reduction learning curve of fixed offshore wind. (2) Technical items: (3) Issues to be solved: Cost to deal with intermittency

<p>Technology: Wind power</p> <ol style="list-style-type: none"> <li>(1) Reason: Wind energy supply is plagued by intermittency.</li> <li>(2) Technical items: Needs to be coupled to safe cost-effective energy storage systems such as batteries, CAES, or PHS. In addition, ongoing environmental concerns need to be addressed regarding land- and ocean-based wind farms.</li> <li>(3) Issues to be solved: Battery storage safety, efficiency, and longevity. High-efficiency turbines to recover energy from CAES. Reduced construction timelines, cost, and environmental acceptability of PHS systems.</li> </ol>
<p>Technology: Off Shore and Floating off shore wind</p> <ol style="list-style-type: none"> <li>(1) Reason: Huge potential to meet total energy needs in combination with hydrogen production and hydrogen generation</li> <li>(2) Technical items: Platforms, transportation of energy, integration with grid</li> <li>(3) Issues to be solved: Installation, maintenance, HVDC systems in the ocean, integration with the grid, hydrogen</li> </ol>
<p>Technology: Offshore wind</p> <ol style="list-style-type: none"> <li>(1) Reason: less controversial compared to on-shore wind</li> <li>(2) Technical items: subsea and offshore technologies, increased voltage levels</li> <li>(3) Issues to be solved:</li> </ol>
<p>Technology: Renewable energy</p> <ol style="list-style-type: none"> <li>(1) Reason: Reduction of environmental load</li> <li>(2) Technical items: Wind power generation, biomass, etc.</li> <li>(3) Issues to be solved: Technology development is required to reduce costs, etc.</li> </ol>
<p><b>Ocean energy</b></p>
<p>Technology: Ocean Energy</p> <ol style="list-style-type: none"> <li>(1) Reason: technology is in its infancy</li> <li>(2) Technical items: tracking the deployments globally</li> <li>(3) Issues to be solved: technology maturity</li> </ol>
<p><b>LNG</b></p>
<p>Technology: LNG</p> <ol style="list-style-type: none"> <li>(1) Reason: Some nations have embraced use of LNG as an energy source, but public concerns persist in others, particularly regarding safe transportation and storage of LNG.</li> <li>(2) Technical items: Determination and demonstration of adequacy of systems and regulations related to transportation hazards, risks, and safety. Determination and demonstration of adequacy of systems and regulations related to environmental protection under accident conditions.</li> <li>(3) Issues to be solved: Independent quantitative evaluation of transportation hazards, risks, and safety. Quantitative assessment of safety of train operators (e.g., number of buffer cars between pull and/or push locomotive and first LNG tank car) and associated regulatory controls. Quantitative assessment of environmental impacts of LNG release, fire, and potential explosion.</li> </ol>
<p>Technology: LNG</p> <ol style="list-style-type: none"> <li>(1) Reason: Gas-fired power generation will play an important role as a base load and peaker power source in the increase in renewable energy and decarbonisation.</li> <li>(2) Technical items: To improve the efficiency and reliability of power plants.</li> <li>(3) Issues to be solved: Social understanding of the need for conventional thermal power source.</li> </ol>
<p>Technology: LNG</p> <ol style="list-style-type: none"> <li>(1) Reason: We constructs flexibility combined-cycle power plants to response to the intermittent renewable energy.</li> <li>(2) Technical items: LNG</li> <li>(3) Issues to be solved: Through the government environmental assessment, we construct natural gas storage tanks and combined-cycle units</li> </ol>
<p>Technology: LNG</p> <ol style="list-style-type: none"> <li>(1) Reason: There is no local gas resources, however the neighbouring countries do have resources.</li> <li>(2) Technical items: Security of the primary energy resource, piping to generation station.</li> <li>(3) Issues to be solved: techno-economic feasibility, long term pricing security</li> </ol>

<p>Technology: CCGT</p> <p>(1) Reason: Natural gas and CCGT in particular are interesting energy source which allow to increase higher shares of renewables while providing grid stabilization. It also helps with decarbonisation while shifting from coal to natural gas.</p> <p>(2) Technical items: Hydrogen combustion</p> <p>(3) Issues to be solved: Decarbonisation of natural gas through clean hydrogen produced by electrolysis</p>
<p><b>Coal</b></p>
<p>Technology: Coal</p> <p>(1) Reason: Coal combustion is a major source of CO<sub>2</sub> emissions worldwide. Nevertheless, it continues to be and is anticipated to remain a significant producer of electrical energy throughout the world.</p> <p>(2) Technical items: Carbon capture and sequestration. Carbon capture and conversion.</p> <p>(3) Issues to be solved: In addition to the technical issues of carbon capture and sequestration or conversion, policy issues also should be considered. For example, carbon taxation could incentivize reducing use of coal, investing in capture technologies, and underwriting the cost of R&amp;D to advance these technologies.</p>
<p>Technology: Coal gasification technology</p> <p>(1) Reason: Environmental conservation and effective utilization of fossil resources by improving the efficiency and low carbon of coal-fired power generation</p> <p>(2) Technical items: CO<sub>2</sub> separation/recovery type IGFC</p> <p>(3) Issues to be solved: Verification of basic performance and operability of CO<sub>2</sub> separation/recovery type IGFC is required</p>
<p>Technology: Coal</p> <p>(1) Reason: CCUS has not been put into practical use due to the high cost, although the significance of decarbonization is high. In recent years, low cost has advanced, and development is proceeding toward practical use.</p> <p>(2) Technical items: CCUS</p> <p>(3) Issues to be solved: It is necessary to promote the technology to stakeholder in order to obtain support from people and government.</p>
<p>Technology: Coal</p> <p>(1) Reason: Recently, the environmental regulation is more and more strict. Besides coal fired or oil fired power plants, gas fired power plant needs to setup SCR system to meet emission standards.</p> <p>(2) Technical items: Low temperature deNO<sub>x</sub> catalyst</p> <p>(3) Issues to be solved: Low temperature activity and high efficiency catalyst need to be developed.</p>
<p>Technology: CCU</p> <p>(1) Reason: Alternative use of lignite and use of CO<sub>2</sub> from flue gas of fossil fired power plants</p> <p>(2) Technical items: e-fuel composition and utilisation opportunities</p> <p>(3) Issues to be solved: increasing efficiency of production process and scalability of usage.</p>
<p>Technology: Coal</p> <p>(1) Reason: Construct USC unit for efficiency improvement and environmental protection</p> <p>(2) Technical items: Coal</p> <p>Issues to be solved: A bit polluting emissions are still existing.</p>
<p>Technology: Coal</p> <p>(1) Reason: Coal is abundant and inexpensive with little regional bias, and is a valuable energy source in other energy-poor countries and developing countries that are forced to live without electricity. Coal it emits twice as much CO<sub>2</sub> when compared to natural gas when burned, so its reduction is required. Therefore, we are working on technological development to reduce CO<sub>2</sub> emissions to almost zero.</p> <p>(2) Technical items: CCS/CCUS</p> <p>(1) Issues to be solved: Commercialisation and cost down</p>
<p>Technology: CCS/CCUS, Renewable Energy</p> <p>(1) Reason: Significance of decarbonisation is very high.</p> <p>(2) Technical items:</p> <p>(3) Issues to be solved:</p>

<b>Biomass</b>
<p>Technology : Coal, Biomass</p> <p>(1) Reason: Fossil fuels are still an important energy resource in the process of decarbonisation. New fuel development is needed to achieve both environmental friendliness and economic efficiency</p> <p>(2) Technical items: Biomass mixed new fuel development</p> <p>(3) Issues to be solved: lowering cost</p>
<p>Technology: Biomass</p> <p>(1) Reason: National regulation to switch from coal to biomass (License to operate)</p> <p>(2) Technical items: Feedstocks treatment on-site, incineration process, flue gas component treatment</p> <p>(3) Issues to be solved: Flexibility in feedstock and reduction of efficiency losses</p>
<p>Technology: Biomass</p> <p>(1) Reason: Biomass is carbon neutral fuel</p> <p>(2) Technical items: Mixed combustion, single combustion</p> <p>(3) Issues to be solved: Ash trouble</p>
<p>Technology: Biomass</p> <p>(1) Reason: The electric utility does not have access to the primary energy resource. Therefore, only municipality level interest.</p> <p>(2) Technical items: Access to the resource, logistics and transport costs, repurposing of coal power stations.</p> <p>(3) Issues to be solved: Techno-economics</p>
<b>Nuclear</b>
<p>Technology: Nuclear power</p> <p>(1) Reason: Tightening safety regulations, Reduction of environmental load</p> <p>(2) Technical items: Natural disaster/terrorism countermeasures, decommissioning technology, etc.</p> <p>(3) Issues to be solved: Technology development is required to ensure safety based on new regulatory requirements and cases of natural disasters</p>
<p>Technology: Nuclear</p> <p>(1) Reason: Nuclear power remains the single largest contributor to carbon-free electrical generation.</p> <p>(2) Technical items: Safety concerns persist, largely because of extreme isolated nuclear accidents at Chernobyl and Fukushima Daiichi. Economic concerns also leading to early shutdown of nuclear power plants. Ultimate disposal of radioactive wastes has not been addressed by the major nuclear power producers; only Finland and Sweden are nearing implementation of deep geological disposal.</p> <p>(3) Issues to be solved: Improved technology for evaluating and incorporating beyond-design-basis events in nuclear power plant safety assessments. Licensing, demonstration, and deployment of small modular reactors. Government and industry funding for next-generation nuclear power production systems. National policies and associated funding for site characterization, design, development, and operation of one or more radioactive waste disposal systems.</p>
<b>Others</b>
<p>Technology: Remote monitoring of passive components</p> <p>(1) Aging power plants require increased attention to components not previously inspected. New kinds of power plants (e.g. offshore wind and SMRs) have conditions that make them difficult and even dangerous for direct access by personnel.</p> <p>(2) Technical items: Wall thinning, corrosion under insulation, corrosion under soil/concrete, etc.</p> <p>(3) Issues to be solved: Improvements in guided waves and other inspection techniques, power harvesting and wireless communication.</p>
<p>Technology: PtH</p> <p>(1) Reason: Increase flexibility of existing power plant and enabling up-scaling</p> <p>(2) Technical items: heat storage material, storage management system</p> <p>(3) Issues to be solved: enabling high heat extraction and cost competitiveness.</p>
<p>Not applicable. But based on Meralco's PSPP, we plan to have contracts with power suppliers who use conventional and renewable sources of energy (such as solar PV) depending on our optimal power supply mix.</p>
<p>Technology: green gas (biomethane and hydrogen)</p> <p>(1) Reason: we want to decarbonize our gas infrastructure with green gas over 2050</p> <p>(2) Technical items: operational and maintenance of anaerobic digestion unit, investment in gasification units, development of competitive H2 production technologies</p>

(3) Issues to be solved: cost reduction, large scale production
<b>In your roadmapping approach what are the key emerging technologies that you are considering?</b>
<b>PV</b>
Technology: Advanced Solar
<ul style="list-style-type: none"> <li>(1) Reason: A7 is committed to further decarbonising its asset portfolio under Climate Vision 2050</li> <li>(2) Technical items: Perovskite</li> <li>(3) Issues to be solved: Despite the advantages, perovskites also face a series of technical challenges, such as material degradation and stability, toxicity and environmental impact, manufacturing and deposition techniques.</li> </ul>
<b>Wind</b>
Technology: Advanced Wind
<ul style="list-style-type: none"> <li>(1) Reason: A7 is committed to further decarbonising its asset portfolio under Climate Vision 2050</li> <li>(2) Technical items: Airborne wind energy systems (AWES)</li> <li>(3) Issues to be solved: Activity in the space remains early-stage and it is mostly concentrated around a scattered group of startups and research centres. Early prototype shave set a consistent theoretical basis and revealed challenges around the durability and controlled motion (e.g. take-off, flight and landing). However, in the absence of clear technological differentiation, the key factor to drive growth will be the establishment of strong development and commercialization partnerships.</li> </ul>
<b>Coal</b>
Technology: Carbon capture, utilization and storage (CCUS)
<ul style="list-style-type: none"> <li>(1) Reason: A7 is committed to further decarbonising its asset portfolio under Climate Vision 2050</li> <li>(2) Technical items:</li> <li>(3) Issues to be solved: The global energy transition is presenting a myriad of challenges that the industry has yet to face in its century long history. For examples, high capital and operational costs have plagued CO2 capture projects over the years. Deployment of CO2 capture often results in heavy production penalties due to energy demand. While growing momentum in emissions reduction has renewed interest in CO2 capture, there remains a lack of incentives – either carbon taxes or subsidies – with a high enough financial benefit to offset the existing costs of commercial MEA-based CO2 capture systems.</li> </ul>
<b>Nuclear</b>
Technology: SMR
<ul style="list-style-type: none"> <li>(1) Reason: modularity, reduction of risk, less nuclear waste</li> <li>(2) Technical items:</li> </ul> <p>Issues to be solved: multilateral harmonization, pre-licensing for early regulator feedback &amp; overall process de-risking, new material qualification</p>
Technology: Nuclear
<ul style="list-style-type: none"> <li>(1) Reason: A7is committed to further decarbonising its asset portfolio under Climate Vision 2050</li> <li>(2) Technical items: Small Scale Nuclear</li> <li>(3) Issues to be solved: While SMRs hold promise for stable, scalable power and heat production, the technology has not moved beyond the development stage and pressing questions remain about capital and operating costs. Key issues that will influence the future of SMRs include: <ul style="list-style-type: none"> <li>1) Cost and commercialization</li> <li>2) Competition from renewables and renewable-plus-storage</li> </ul> </li> </ul> <p>Decommissioning and regulatory concerns</p>
Technology: Small Modular Nuclear Reactors
<ul style="list-style-type: none"> <li>(1) Reason: Environmentally sound, deployed near the load</li> <li>(2) Technical items: Demonstration of the technology</li> </ul> <p>Issues to be solved: Technology Maturity</p>
Technology: Biotechnologies

- (1) Reason: production of green fuel
- (2) Technical items: fermenter, bacterial cell selection, increase yield
- (3) Issues to be solved: develop some demonstrator and moving to industrial scale

**What is your policy in coping with social demands related to future technology implementation ?**

- We will develop a new era of electric power business that not only provides a stable supply but also improves environmental friendliness and convenience.

- In A9, the power generation companies and the T/D companies were divided. The stable electricity supply is needed

- In the power transmission and distribution, in order to maintain stable operation of the power system even under the introduction of a large amount of renewable energy, we aim to secure the inertial force of the power system, manage the voltage of the power system, and maintain the power quality.
- For this reason, we are working on research and development on ownership of energy storage system utilizing method for bundling small-scale power generation facilities such as scattered small-scale PVs and resources on the consumer side, and Japanese version of Connect & Manage, which allows connection to the grid under certain conditions, such as controlling the output only during the time period where the free capacity of transmission lines is insufficient.
- In the sales field, we are aiming to develop an environmentally friendly renewable energy sales business model. For example, by combining PV panels, storage batteries, and EVs, we are working on the introduction of a V2X system that can effectively utilize renewable energy in normal times and can be utilized as backup power in the event of a disaster.

- Continue to supply customers with safe and stable electricity at low prices. Therefore, we will build equipment that enables stable power transmission. Specifically, we will promote the sophistication of equipment formation, maintenance and operation, and take measures for equipment (resilience) in preparation for disasters.

- The development of advanced transmission industry is an effective way to solve the contradiction between supply and demand in A2, and it is also the basis for realizing cross regional consumption of clean energy in A2. It should continue to invest in the construction of ultra-high voltage (UHV) projects, which plays an important role in ensuring the power supply, promoting the development of clean energy, improving the environment and enhancing the security level of power grid.

- Distributed energy storage has emerged as an important technology for achieving better integration of clean distributed generation, helping customers manage loads and energy costs, and for providing valuable grid services.
- As costs continue to fall and performance improves, we expect its importance to a modern grid will only grow.
- The field is both growing and shrinking as startups emerge with new offerings and companies in the field are acquired by competitors.

- The ownership of energy storage system is essential. At this moment, TSO and DSO cannot own and operate the energy storage system but the energy storage system could be good options to solve the problems such as congestion caused by renewable energy.

- As shares of renewable energy on overall energy production will increase, grid stabilization will be crucial issues regarding T/D and retail. Energy storage devices such as batteries, pumped hydro and hydrogen will play a major role in grid stabilisation where common techniques won't be sufficient.
- Centralized and decentralised power generation will go hand to hand with optimization of grid stability, distribution and transmission. At locations where it is suitable, decentralization can support self-sufficient communities. Technologies such as prosumers, smart grids and smart house will also take a part in grid balancing and renewable energy inclusion.

<ul style="list-style-type: none"> <li>• It is expected that there will be risks lowering electricity quality such as system voltage im-balance and frequency fluctuation due to the expansion of the introduction of renewable energy.</li> <li>• On the other hand, utilities have a social proposition of saving operation costs. Therefore, it is necessary to introduce a system (Including Iot technology) which contributes to improving electricity quality and operation efficiency while utilizing existing network facilities in order to prevent capital investment in T&amp;D from getting excessive.</li> </ul>
<ul style="list-style-type: none"> <li>• Regarding the utilization of electricity that is environmentally friendly and convenient, it is necessary to promote electrification in all fields, such as the electrification of transportation energy due to the spread of electric vehicles, in addition to industrial, commercial and household use.</li> <li>• It is necessary to utilize power storage technology and optimize power control in anticipation of diversifying power transaction forms such as the spread of distributed power sources and transactions between individuals.</li> </ul>
<ul style="list-style-type: none"> <li>• Resiliency is critical and becoming more critical. With climate change there is concern that there will be more long duration outages. Wildfires in California and the increasing number of storms are examples.</li> <li>• There is an expectation that we can accommodate and integrate more and more renewables. We need to have planning and operations tools for this integration.</li> <li>• Electrification is the next major decarbonisation strategy – there will be infrastructure upgrades necessary to deal with this but we have to optimize the investments based on the ability to manage demand.</li> <li>• Community energy management and local micro-grids are ways to engage customers and communities. These are new design challenges for the distribution system.</li> <li>• As part of the resiliency strategy and also for analytics, there will be an increasing pressure for undergrounding.</li> <li>• We have to figure out ways to align electricity rates and prices with grid and generation needs for flexibility. This has regulatory implications but also technical issues.</li> </ul>
<ul style="list-style-type: none"> <li>• Demonstration and promotion of introduction of VPP technology toward becoming the main power source for renewable energy.</li> <li>• Establishment of the technologies provided by asynchronous machines, such as inertia, synchronization power, voltage adjustment, and accident current supply, which have been provided by conventional synchronous machines, toward becoming the main power source of renewable energy, in addition to measures for surplus power and frequency,</li> <li>• Construction of a flexible autonomous micro-grid that utilizes EV, which is a movable distributed power source, in addition to distributed power sources such as renewable energy and storage batteries.</li> <li>• As a measure against surplus electricity due to renewable energy, it may be necessary to develop a large-capacity, low-cost energy storage device in addition to utilizing hydrogen.</li> <li>• Isn't it necessary to reduce the cost of storage batteries, increase the energy density, and establish recycling/reuse technology for mass diffusion?</li> <li>• Isn't it necessary to reduce the cost of distributed resource (DER) monitoring/control technology and integrated control technology (including communication) such as EMS?</li> </ul>
<p>Conversion to next-generation network</p> <ul style="list-style-type: none"> <li>• High efficiency and resilience of the entire power network</li> <li>• Optimization of equipment and operation that takes advantage of the distributed system for local production for local consumption</li> <li>• Adaptation to expansion of large-scale and uneven distribution renewable energy power source, and pursuit of nationwide stable supply and wide-area merits</li> </ul>
<ul style="list-style-type: none"> <li>• Residential customers have seen a spike in electricity usage and consumption due to ‘work from home’ and online education during the lockdown imposition and quarantine measures. This trend is expected to gain traction post-pandemic and will promote prosumer policies and programmes for the end-users.</li> <li>• Some of the DU’s plans and initiatives to support the increasing uptake of DER integration in the system are the implementation of micro-grid technologies and Battery Energy Storage Systems (BESS) projects, especially to provide power to island communities. For inland electrification, solar home system (SHS) is a viable option to provide those in remote and far-flung areas with access to reliable and clean energy. To support these initiatives, implementation of grid modernization plans, such as Advanced Network Automation, Advanced Metering Infrastructure, DER Integration systems, are key imperatives for Meralco to meet the ever-changing customer expectations.</li> </ul>
<ul style="list-style-type: none"> <li>• With the rapid increase in PV under the FIT system becoming an expiration of FIT, the shift to the FIP system, and the increase in the number of storage batteries installed, many consumers will become prosumers with DER in the future, and surplus electricity will be used for P2P, etc. Social demands for trading are expected to increase.</li> <li>• In preparation for such a game change in the business environment, we will accumulate the latest knowledge and technology through VPP-related research using device control technology on the demand side and studying the use of DER such as EVs</li> </ul>

<p>and storage batteries, and meet diversifying needs. We will promote technological development that will lead to the solutions.</p>
<ul style="list-style-type: none"> <li>• It will be an important technology to accurately grasp the voltage and current and frequency of the system, evaluate the system status in real time (create a digital twin of the system), and control the generator and inverter appropriately with the increase in the power generation ratio of renewable energy, In addition, energy storage systems such as batteries and load control on the consumer side by increasing the electrification rate are also important.</li> </ul>
<ul style="list-style-type: none"> <li>• The electricity demand increases gradually every year, however, building new power plants can raise a lot of environmental issues. It is believed that consumer's awareness on their own energy usage helps with electricity reduction. As a result, the promotion of AMI has been listed as an important item in Taiwan in the past years. The goal is to install 3 million Smart Meters by 2024 and more than 60% of total electricity energy will be accounted for. Customers can receive the real-time energy usage via Route B that is provided by the Home Area Network (HAN) module placed with the Smart Meter or past day data with a mobile APP provided by the utility. Other measures such as virtual power plants and demand response, etc. have also been promoted.</li> <li>• There are several key challenges to achieve the top policy for energy mix in 2025 of 50% Gas, 30% Coal-fired, and 20% Renewable. Above all, our smart grid accommodates the installation capacity and the penetration of PV system to 20GW as well as the proportion of renewable energy reach 20% in 2025. To cope with the demand, we need our power grid more flexible and resilient. We should prepare sufficiently hosting capacity for the renewables, secure our power system and guarantee local (feeders) stability. For the distribution network, feeder hosting capacity analysis and visualization includes the modelling for PV, EV and BESS and the platform implementation of detailed interactive GIS hosting capacity. In addition, the electricity sales department has to promote new and innovative applications to customers along with TPS's AMI installation and investment such as xEMS (HEMS/BEMS/CEMS), EV, BESS, Demand Response and other coordination issues.</li> <li>• Taiwan's energy transition plan has long term and short-term strategies. The government leads industries and all people moving forward for the goal 2025 renewable energy power generation increase to 20%, natural gas power generation up to 50%, and the coal-fired power generation will decrease to 30%. To achieve the above target, there are many challenges and we are ready for them. First, energy exploration is essential as well as energy diversity. Secondly, we need to strengthen the construction of the power grid so that distributed energy recourse can be smoothly integrated into grid.</li> <li>• In addition, to ensure stable power supply with high-ratio renewable energy on-grid, we will use the newest information &amp; communication technology and power technique to change the traditional power grid into smart grid. These are keys for energy transition, and Taipower Company will apply ourselves to the target.</li> <li>• The research topics we interested are using power system simulation and hardware-in-loop (HIL) test to analyse the interaction between equipment and network. The analysis result is used to adjusting the parameters of equipment and network and contingency scenarios.</li> </ul>
<ul style="list-style-type: none"> <li>• The construction of information infrastructure represented by intelligent sensing communication is connected to huge investment and demand at one end, and to the constantly upgrading consumer market at the other end and is critical force for economic growth and a new engine for promoting high-quality economic development, including the reliable operation of the national large-scale energy metering system, the implementation of tiered electricity prices, the construction of smart cities and smart homes, the automatic reporting of power outages of residential users, the automatic collection and payment of electricity, water, gas, and heat energy, and the orderly charging of charging piles. All applications require safe, reliable, economical, and flexible communication support, and higher requirements are put forward for data collection, communication and deepening applications of integrated energy information.</li> <li>• Smart grid is the inevitable trend for power grid development, with strong ability to optimize the allocation of resources and a higher level of safe and stable operation. Smart grid can realize the convenient interaction between power users and power grid and form the intelligent power interactive platform, to consummate demand side management and provide high-quality power services for users. Society should introduce relevant policies to further realize the information and lean of power grid management, and enhance the capacity of status monitoring, state evaluation and data management of power grid.</li> <li>• At present, the number of electric vehicles in A2 is growing rapidly, and the charging load of electric vehicles has already brought a certain burden to the power grid. In the future, the impact of its access to the power grid for charging will further expand. The adjustable potential of electric vehicles as mobile energy storage has not yet been fully utilized. Relevant studies have shown that orderly charging of electric vehicles provides auxiliary services, including delays in grid construction and emergency backup. In the future, the development of large-scale electric vehicles should focus on the synergy of EV, charging facilities, traffic and grid (vehicle pile road network), and give full play to the mobile energy storage characteristics of electric vehicles. At present, the relevant architecture, interface, strategy and other aspects need to be further studied to support practical applications.</li> <li>• Electricity generation, heating, cooling, and storage solutions connected to distribution grids, interacting with smart homes, smart meters, EVs, and peer-to-peer trading offer a vision of disruptive change. The existing electricity market design is misaligned with technological development. The sharp increase of renewables in the energy system, together with its physical</li> </ul>

<p>characteristics: ‘more variable, less predictable and decentralized’ are some of the reasons behind the revision of Electricity Retail Market rules. The policy of striking the right balance between the verticality and horizontality of future retail market is needed to make competition effective.</p> <ul style="list-style-type: none"> <li>• With the transformation of distributed power system, the importance of power information network is becoming more and more prominent. Different from centralized power system, distributed power system requires access of massive equipment in real-time, where the optical fibre private network is not technically and economically applicable. It is urgent to conduct research on new access technology to solve the problem of equipment in distributed power system.</li> <li>• Since the 1980s, wireless access technology has experienced five generations of development. Recently, wireless access technology is evolving towards ultra-high bandwidth, massive connection and ultra-low latency. We should apply these technologies to power systems and study wireless access to meet the needs of distributed power systems.</li> <li>• 6. With more and more renewable energy transmitted by HVDC or VSC HVDC, the protection scheme for HVDC and VSC HVDC needs to be re-evaluated. Faster protection algorithm should be studied to protect the primary devices and the system more effectively.</li> </ul>
<ul style="list-style-type: none"> <li>• The cost of grid electricity is increasing above inflation. The reliability of the grid over the past decade has become an issue for economic development. Increased interest in PV, inverter and storage technologies.</li> <li>• The cost of PV systems requires a significant capital outlay. Storage technologies are still immature and expensive. The cost of ICT is the largest globally.</li> </ul>
<ul style="list-style-type: none"> <li>• Electrification is an important part of the solutions, regardless of energy sources. T&amp;D infrastructure will become increasingly important.</li> </ul>
<p><b>How do you promote roadmaps technology outputs by way of its (1) the reason, (2) technical items, (3) issues to be solved?</b></p>
<p><b>Battery</b></p>
<p>Technology: Ancillary services</p> <ol style="list-style-type: none"> <li>(1) Reason: Because the amount of renewable energy becomes bigger and bigger</li> <li>(2) Technical items: Control, Battery</li> <li>(3) Issues to be solved: Stability, stable electric supply</li> </ol>
<p>Technology: Energy storage</p> <ol style="list-style-type: none"> <li>(1) Reason: Thermal, mechanical, and chemical energy storage technologies that are GW-scalable with longer durations than batteries are needed.</li> <li>(2) Technical items: Thermal energy storage, pumped heat energy storage, liquid air energy storage, compressed air energy storage, pumped hydro storage, hydrogen production and storage.</li> <li>(3) Issues to be solved: Low Technical Readiness Level, technologies need validation and system demonstrations</li> </ol>
<p>Technology: Energy storage (both electrical and thermal)</p> <ol style="list-style-type: none"> <li>(1) Reason: In sites where primary aim is securing of district heating supply (CHP plants) is desirable to decouple production of electricity and heat to increase source flexibility, respectively mitigate forced electricity production in time when it is not desired.</li> <li>(2) Technical items: Energy storage, ETES, LAES, Hot water tanks</li> <li>(3) Issues to be solved: PV power generation coupled with energy storage creating complex and robust system with stable electricity supply or supply on demand; Round trip efficiency of electrical energy storage and implementation of large scale technologies.</li> </ol>
<p>Technology: Battery Storage</p> <ol style="list-style-type: none"> <li>(1) Reason: Increase flexibility and enabling value stacking</li> <li>(2) Technical items: Energy system &amp; battery management systems, battery system components (e.g. Redox-flow stacks, electrolytes)</li> <li>(3) Issues to be solved: gain operational experience, efficiency options and cost reduction.</li> </ol>
<p>Technology: Battery</p> <ol style="list-style-type: none"> <li>(4) Reason: Due to the increase in EV vehicles in the future, it is expected that used storage batteries, which are cheaper than new ones, will be distributed. These reused storage batteries will be reused to absorb fluctuations in the output of renewable energy.</li> </ol>

(5) Technical items: reuse • Safety evaluation
(6) Issues to be solved: Residual performance/safety evaluation of used batteries
Technology: Long duration batteries
(1) Reason: The LiB is good for short duration application such as frequency control but there are applications which need long duration batteries.
(2) Technical items: Sodium sulphur battery, flow battery
(3) Issues to be solved: High CAPEX
Technology: Battery
(1) Reason: The power quality and stability of off-shore islands are vulnerable. Since the energy usage is low, with high penetration of renewable energy, the impact is high when a traditional generator is tripped.
(2) Technical items: micro-grid, energy storage system
(3) Issues to be solved: Stable energy storage systems that can provide frequency and voltage regulation.
<b>DSM/VPP</b>
Technology: VPP
(1) Reason: IBy utilizing various facilities owned by customers for VPP and DR, it is possible to contribute to solving social issues such as expansion of renewable energy, reduction of energy consumption, and improvement of resilience in the event of an emergency disaster.
(2) Technical items: Frequency control, storage battery control
(3) Issues to be solved: Short-time frequency control, multi-specification battery control technology
Technology: DSM/VPP
(1) Reason: The electrification of large vehicles (route buses, trucks, etc.) has not been widely spread due to operational and introduction cost issues. Therefore, we will develop a large-capacity charger/discharger for large vehicles and support the introduction of electric vehicles (electric buses, electric trucks, etc.) by businesses to promote electrification in the transportation sector.
(2) Technical items: Development of large-capacity charger/discharger for large vehicles
(3) Issues to be solved: Application to energy management
Technology: VPP
(1) Reason: Demand side control, VPP
(2) Technical items: Distributed power control, market power supply utilizing industrial storage batteries
(3) Issues to be solved: It is necessary to accumulate technical knowledge for commercialization
Technology: Demand Response (DR)
(1) Reason: Bucking system is challenging, such as coal fired, LNG, hydro power and nuclear. The most efficient and effective way is to greatly engage with customer side or demand side management, for electricity saving and demand responses. (2) TPC provides various load management programmes, including scheduled, emergency and demand bidding for customers to participate in DSM. We further design and launch ancillary services-oriented demand responses to alleviate the grid impact from renewable energy instability.
(2) Technical items: Potentials in high voltage customers is saturated and we need to deeply investigate individual management or improvement. (2) Launch programmes and recruit low voltage(residential) customers along with AMI deployment.
(3) Issues to be solved: Increase AMI coverages and awareness of customer's electricity use. (2) Design various and tailored incentive programmes for potential customers. (3) Clarify and Coordinate DR purposes between load management and ancillary service.
Technology: Industrial Demand Response
(1) Reason: High energy consumption industrial load accounts for more than 60% of the total national power load, It is an important technical direction to realize carbon neutral strategy to develop electric power demand response in industrial field.
(2) Technical items: Industrial demand response, carbon neutral
(3) Issues to be solved: A fare system that enables industrial enterprise for DSM.
Technology: Demand Response
(1) Reason: In the context of carbon neutral strategy and energy Internet environment, demand response will play an increasingly important role in peak shaving and valley filling and new energy consumption scenarios.
(2) Technical items: OTEC
(3) Issues to be solved: The value mining and transaction of multi-type adjustable load resources need to be solved.
<b>Hydrogen</b>

<p>Technology: Hydrogen</p> <p>(1) Reason: Long term solution for decarbonisation in combination with renewables</p> <p>(2) Technical items: Production, transport, use</p> <p>(3) Issues to be solved: Reducing electrolyser costs, overall energy ecosystem, transport, new fuel cell based appliances</p>
<p>Technology: PtX/Hydrogen</p> <p>(1) Reason: Sector coupling of energy, mobility and industry and increasing flexibility due to in-creased renewables in future.</p> <p>(2) Technical items: Conversion technologies (gasification for waste to hydrogen, storage in salt caverns, system management and control, scaling up electrolyser assets)</p> <p>(3) Issues to be solved: Reduction of costs of sustainable produced hydrogen.</p>
<p>Technology: Hydrogen</p> <p>(1) Reason: hydrogen is critical in the use of and applied to renewables and carbon-free energy solutions. ... A6 aims at operating across the entire value chain of renewable hydrogen, from carbon-free power generation to the three key end uses: mobility, industry and energy storage.</p> <p>(2) Technical items:</p> <p>(3) Issues to be solved: cost of electrolysis</p>
<p>Technology: Hydrogen</p> <p>(1) Reason: Hydrogen is a form of renewable energy storage but currently has high cost, material compatibility challenges, and at high concentrations, requires development of new pipeline infrastructure and compression/combustion technologies.</p> <p>(2) Technical items: Pipeline infrastructure, compression, and combustion.</p> <p>(3) Issues to be solved: High cost of H<sub>2</sub> production, loss in energy capacity of pipelines, increased compression power and speed requirements, NO<sub>x</sub> emissions and leakage, and fire and explosion hazards.</p>
<p>Technology: Hydrogen</p> <p>(1) Reason: Hydrogen represent a means of carrier which can connect electrical and natural gas grid.</p> <p>(2) Technical items: Sector coupling</p> <p>(3) Issues to be solved: Technologies adjustment for hydrogen implementation into certain sectors.</p>
<b>Super grid</b>
<p>Technology: Super Grid</p> <p>(1) Reason: Long distance offshore wind power energy transmission</p> <p>(2) Technical items: HVDC</p> <p>(3) Issues to be solved: The cost is too high</p>
<p>Technology : HVDC</p> <p>(1) Reason: Because the renewable energy sites should be connected to the big cities by HVDC</p> <p>(2) Technical items: HVDC</p> <p>(3) Issues to be solved: There is the technology of HVDC, already.</p>
<p>Technology: Fast HVDC transmission line protection</p> <p>(1) Reason: The fault characteristic of the HVDC system changes a lot with new energy control devices.</p> <p>(2) Technical items: Fast HVDC transmission line protection.</p> <p>(3) Issues to be solved: A more sensitive and fast operation protection scheme for the HVDC transmission line protection.</p>
<b>Smart grid</b>
<p>Technology: Smart Grid</p> <p>(1) Reason: In order to stabilize the power supply, improve the effective use of energy, and achieve energy saving goals.</p> <p>(2) Technical items: IEC 61850</p> <p>(3) Issues to be solved: Integration of new and old equipment, applications, technologies, and devices.</p>
<p>Technology: Smart Grid</p> <p>(1) Reason: It is necessary to improve controllability and increase power transfer capability of grid because of high proportional renewable energy.</p> <p>(2) Technical items: FACT</p> <p>Issues to be solved: FACT design and control</p>

<p>Technology: Intelligent Distributed Feeder Automation</p> <p>(1) Reason: The intelligent distributed feeder automation can effectively improve the reliability of distribution network.</p> <p>(2) Technical items: Slow distributed feeder automation system</p> <p>(3) Issues to be solved: A reliable communication mode</p>
<p>Technology: Smart grid</p> <p>(1) Reason: Due to the pressure of environmental protection and energy depletion, clean renewable energy should be vigorously developed. Smart grid technology can realize the flexible and efficient application of distributed power supply. The construction of smart grid needs advanced sensor measurement technology as support. On-line monitoring and status evaluation of power equipment can ensure accurate acquisition of data and information, through which we can control the actual operation efficiency of high voltage equipment, ensure the real-time transmission of data and information, and improve the security and stability of smart grid.</p> <p>(2) Technical items: On-line Monitoring and State Evaluation of Sensor Equipment</p> <p>(3) Issues to be solved: The performance of sensor equipment is related to information sensing and stable operation of smart grid. To realize the on-line monitoring of sensor equipment, we need to study more accurate mathematical model and intelligent algorithm of on-line monitoring and deepen the on-site application of on-line monitoring and techniques. Data collected by different pilot stations cannot be transmitted effectively, which makes the data between stations unable to be analysed in depth mining. This will lead to difficulties in the development of transformer big data analysis. It is necessary to do in-depth research on the accurate evaluation and wide-area analysis of the operating transformer's measurement performance, improvement of measurement performance evaluation method. On this basis, large-scale pilot application verification and dynamic data depth analysis mining should be carried out to realize data analysis and application of wide area system and support smart grid development.</p>
<p>Technology: Integrated Grid - Smart Grid integrating smart communities, micro-grids and distributed resources and intelligent infrastructure</p> <p>(1) Reason: Renewable integration and electrification are keys to decarbonisation – the grid must be planned and operated in an optimum manner with these distributed resources.</p> <p>(2) Technical items: Communications, smart technologies, planning tools, real time operations tools, resiliency</p> <p>(3) Issues to be solved: New planning tools, new operations systems (DERMS and distributed DERMS), advanced DMS</p>
<p>Technology: Sensor terminal</p> <p>(1) Reason: For the application scenarios in the field of low-voltage distribution, the low-voltage full state sensing terminal can meet the requirements of topology dynamic identification of low-voltage distribution station area, user electrical characteristics, etc.</p> <p>(2) Technical items: Identification and perception terminal</p> <p>(3) Issues to be solved: Low power consumption and life.</p>
<p>Technology: ANM(Active Network Management System)</p> <p>(1) Reason: Online management of distributed resources is indispensable to reduce infrastructure costs</p> <p>(2) Technical items: Active network management software development with high speed OPF calculation</p> <p>(3) Issues to be solved: increase the integration amount of renewable at the distribution level</p>
<p>Technology: Smart Grids, DSM, Micro-grid,</p> <p>(1) Reason: Brining about efficiency, lots of interest. Lots of research and piloting.</p> <p>(2) Technical items: Capital constrains to invest into the technology</p> <p>(3) Issues to be solved: finance</p>
<p>Technology: Telecom</p> <p>(1) Reason: In response to the promotion of smart grids, communication related technologies need to be developed.</p> <p>(2) Technical items: 5G, Cyber security, Optical fibre communication</p> <p>(3) Issues to be solved: 5G and optical fibre deployment costs are high, and there have cyber security concerns.</p>
<p>Technology: High-speed power line carrier (HPLC)</p> <p>(1) Reason: HPLC technology with the two major characteristics of high speed and interconnection will not only solve the communication speed, reliability, and interconnection requirements, but also lead the direction of cross-industry, multi-sensing IoT application scenarios in the field of power line carrier.</p> <p>(2) Technical items: high speed, interconnection</p> <p>(3) Issues to be solved: High frequency data acquisition (Read 300 smart meters every 15 minutes), power failure report (success</p>

rate 90%), clock management, area network recognition, etc.
Technology: HPLC & HRF dual mode communication
<p>(1) Reason: Dual-mode communication integrates the dual advantages of HPLC and HRF. It can automatically switch between PLC and RF channels based on communication quality, eliminating communication blind spots.</p> <p>(2) Technical items: PLC+RF</p> <p>(3) Issues to be solved: High frequency data acquisition, accurate power failure report (success rate 99.9%), orderly charging of EV, home appliances metering, etc.</p>
<b>Smart Building/town/CPS</b>
Technology: xEMS (HEMS/BEMS/CEMS)
<p>(1) Reason::xEMS manages energy consumption and achieves value-added service into communities, building and living. (2) xEMS provides portfolio to aggregate demand capacity with open ADR VTN/VENs architecture. (3) Enhance Big data analytics and emerging business development.</p> <p>(2) Technical items: The xEMS technology is well developed in A18 after projects supported by the government have been finished.</p> <p>(3) Issues to be solved: The return of investment needs to be shortened and we have to offer new EMS operation models. (2) ESCO and Aggregator industry which help making the best use of EMS technology need to be promoted.</p>
<b>Smart city</b>
Technology: Smart city
<p>(1) Reason: Decentralized power generation and distribution can help to establish self-sufficient communities which might be powered from low emission source to large extent.</p> <p>(2) Technical items: Equipment connectivity</p> <p>(3) Issues to be solved: Smart city are depended on local conditions so far which makes them harder to set at large scale.</p>
Technology: Smart Community
<p>(1) Reason: Community engagement is critical for many societal goals in the future – poverty, food, housing, entertainment, energy, decarbonisation, resiliency, etc. There are tremendous opportunities for optimization across diverse systems at the community level.</p> <p>(2) Technical items: Communications, platforms for integration, data</p> <p>(3) Issues to be solved: sensors, communications infrastructure, platforms, integration, data, AI</p>
Technology: Research on the interaction strategy between large-scale electric vehicles and the grid
<p>(1) Reason: At present, most EV charging is disorderly charging, and orderly charging is only used in pilot projects in some residential communities.</p> <p>(2) Technical items:</p> <ol style="list-style-type: none"> <li>① Orderly charging and dispatchable potential online assessment technology;</li> <li>② Orderly charging intraday and day-ahead coordinated control strategy;</li> <li>③ Vehicle, pile, and grid-side support technologies that support the realization of V2G;</li> <li>④ V2G emergency dispatch and power grid Adjust linkage strategy.</li> </ol> <p>(3) Issues to be solved: Fully explore the mobile energy storage potential of electric vehicles, reduce the impact of charging on the grid, and even provide auxiliary services for the grid.</p>
<b>Others</b>
Technology: SF6 free circuit breaker/switchgear
<p>(4) Reason: Environmental factor (Carbon free)</p> <p>(5) Technical items: Vacuum circuit breaker/Vacuum dry air switchgear</p> <p>(6) Issues to be solved: Non SF6 product</p>
<b>Battery</b>
Technology: Batteries – Redox Flow batteries
<p>(1) Reason: Drive not only towards cheaper but more sustainable and safer battery chemistries</p> <p>(2) Technical items:</p> <p>(3) Issues to be solved: cost and risk of leakage</p>
Technology: Alternative Storage Technologies
<p>(1) Reason: Understanding the development of competing technologies to Lithium-Ion battery technologies</p> <p>(2) Technical items: stationary systems and battery setups (different electrolytes and anodes/cathodes)</p>

(3) Issues to be solved: Cost reduction potential and time to market understanding
Technology: Grid-scale energy storage
<p>(1) Reason: The growth of renewable energy continues. Grid-storage batteries are motivated by utility-scale wind and solar installations to help firm short-term operating frequency and balance longer-term load.</p> <p>(2) Technical items: Li-ion, Sodium-sulphur, Flow, Zinc-air, Compressed Air, Hydrogen</p> <p>(3) Issues to be solved: Falling prices is needed in order for energy storage system playing a key role in the power system. Higher power systems and longer durations will also emerge as more critical requirements. In addition, lacking of policies supporting application stacking and hydrogen economy have to be addressed.</p>
Technology: Battery Energy Storage System (BESS)
<p>(1) Reason: To cope with the renewable energy fluctuations, to accommodate system frequency stability and to act as various kinds of ancillary services resources, BESS is going to be the key role of distribution energy, DR, VPP and micro grid.</p> <p>(2) Technical items: Coordination and optimization for Batteries, BMS (Battery Management System) and PCS (Power Conditioning System). (2) Test various kinds batteries with a variety of functions and evaluate how well the BESS is as an ancillary device.</p> <p>(3) Issues to be solved: We aim to install more than 590MW in power grid by 2025. (2) For localization, battery will be produced in Taiwan. (3) Market requirements and applications are currently limited in Taiwan. (4) Cost benefit initiatives are not enough.</p>
Technology: Distributed energy storage/PV (community and building)
<p>(1) Reason: Local community energy optimization opportunities and participation in grid flexibility requirements</p> <p>(2) Technical items: integrated energy optimization, flexibility markets (local and wholesale markets)</p> <p>(3) Issues to be solved: Cost, flexibility markets, local energy optimization platforms</p>
<b>Hydrogen</b>
Technology: Hydrogen
<p>(1) Reason: Hydrogen has a potential to decarbonized not only power generation sector but also other sector such as transportation, chemical and steel industry and heat generation. Even though it is not a source and it's rather carrier, it has great amount of possibilities to implement.</p> <p>(2) Technical items: Natural gas replacement and energy storage</p> <p>(3) Issues to be solved: There is several things which needs to be solved regarding hydrogen technologies. Security of technology, modification of existing gas infrastructure, converting current technologies on hydrogen and economy improvement are crucial for further implementation. Pilot projects are important at this stage.</p>
Technology: Hydrogen, Ammonia
<p>(1) Reason: Because they are next generation energy for utilization and excess energy power.</p> <p>(2) Technical items: To improve storage capability.</p> <p>(3) Issues to be solved: To increase players and customers in the market. It is necessary to boost the technology in order to obtain funding from the government.</p>
Technology: Other H <sub>2</sub> technologies
<p>(1) Reason: Competing technologies to electrolyzers such as CH<sub>4</sub> pyrolysis, steam methane re-forming with CCS (blue H<sub>2</sub>), hydrogen carrier materials, conversion technologies (e.g. ammonia to hydrogen)</p> <p>(2) Technical items: alternative CH<sub>4</sub> pyrolysis technologies, Carbon usage market, blue H<sub>2</sub> markets</p> <p>(3) Issues to be solved: understanding cost competitiveness of green hydrogen</p>
<b>Super grid</b>
Technology: DC
<p>(1) Reason: The growth of renewable energy continues. HVDC is a well-commercialized technology with an established history in the offshore wind industry and increasingly in long-distance power transmission and with renewables projects around the world.</p> <p>(2) Technical items: High-voltage direct current (HVDC)</p> <p>(3) Issues to be solved: High-voltage direct current technology hasn't yet reached its zenith, because developers are still testing creative implementations so that the technology can provide active grid balancing instead of just carrying power. At its heart the technology is fundamentally useful – though more expensive than high-voltage AC per mile, it will be necessary for</p>

achieving higher renewables penetration.
<b>Smart grid</b>
Technology: Energy Management for smart Loads (especially EV Charging)
<ul style="list-style-type: none"> <li>(1) Reason: Important element of overall demand management strategies</li> <li>(2) Technical items: Platforms for smart device integration</li> <li>(3) Issues to be solved: Integration of demand management with distribution management, markets and third-party services (aggregators, etc.)</li> </ul>
Technology: DC
<ul style="list-style-type: none"> <li>(1) Reason: The growth of renewable energy continues. While there are instances of DC microgrids powering buildings such as data centres or manufacturing facilities, innovation for the technology has been more common in the developing world, where there may be fewer loads that would require AC power.</li> <li>(2) Technical items: DC Micro-grids DC Micro-grids</li> <li>(3) Issues to be solved: high initial costs with uncertain cost recovery</li> </ul>
Technology 1: DC grid
<ul style="list-style-type: none"> <li>(1) Reason: Power electronic is mature to support DC grid</li> <li>(2) Technical items: DC distribution network</li> <li>(3) Issues to be solved: Low emission reducing distribution/conversion losses</li> </ul>
Technology 2: Wireless
<ul style="list-style-type: none"> <li>(1) Reason: Cables is a big constrain in the distribution of electricity</li> <li>(2) Technical items: wireless distribution</li> <li>(3) Issues to be solved: High benefit for final user, high safety</li> </ul>
Technology 1: Micro-grids
<ul style="list-style-type: none"> <li>(1) Reason: Electrification in remote areas. Have done research and large-scale pilots.</li> <li>(2) Technical items: Costs</li> <li>(3) Issues to be solved: Costs</li> </ul>
Technology: Digital Twin for Grid Management
<ul style="list-style-type: none"> <li>(1) Reason: Opportunity for optimization through real time condition information and advanced data analytics</li> <li>(2) Technical items: Widespread sensors with communications infrastructure, data management, platforms for integration, data analytics, advanced system modelling.</li> <li>(3) Issues to be solved: Data integration, real time state estimation, advanced models for customers and communities, control system integration</li> </ul>
Technology: inertial force
<ul style="list-style-type: none"> <li>(1) Reason: Ensuring inertial force due to expansion of renewable energy</li> <li>(2) Technical items: Pseudo-inertial force technology</li> <li>(3) Issues to be solved: It is necessary to develop technology related to improving demand forecast accuracy and tidal current monitoring.</li> </ul>
Technology: Edge Computing
<ul style="list-style-type: none"> <li>(1) Reason: In the era of renewable energy, grid-edge devices needs to have the capability of communicating with one another in order to make a decision instantly to cope with the sudden changes instead of sending every bit of data back to the central station.</li> <li>(2) Technical items: Open FMB</li> <li>(3) Issues to be solved: More and more devices of different manufactures are installed in the grid-edge but lack of interoperability capability.</li> </ul>
Technology: Telecom
<ul style="list-style-type: none"> <li>(1) Reason: Places where power generation/power consumption data cannot be returned as a power backup mechanism.</li> <li>(2) Technical items: Satellite communications</li> <li>(3) Issues to be solved: Satellite communications are easily affected by the climate, and the construction costs are high.</li> </ul>

<p>Technology: Digitalization</p> <p>(1) Reason: Improved plant performance, better asset management, reduction in operating costs.  (2) Technical items: Access to capital  (3) Issues to be solved: financial constraints</p>
<b>Smart city</b>
<p>Technology: Smart city</p> <p>(1) Reason: Decentralized power generation and distribution can help to establish self-sufficient communities which might be powered from low emission source to large extent.  (2) Technical items: Equipment connectivity  (3) Issues to be solved: Smart city are depended on local conditions so far which makes them harder to set at large scale.</p>
<p>Technology: EV</p> <p>(1) Reason: Because the amount of EV becomes bigger and bigger  (2) Technical items: Control of battery  (3) Issues to be solved: Cooperation with the electric power system</p>
<p>Technology: Electric Vehicle (EV)</p> <p>(1) Reason:  EV can improve low carbon emissions and air pollution. (2) EV enables innovative technologies and further to V2G as the distributed movable energy storage system.  (2) Technical items:  Distribution network capacity, facility preparation and security issues. (2) Charging pile and station locations, standard, protocol and tailored TOU. (3) Reinforcing demand side management with precise TOU price signal (G2V and V2G) or DR signal to reduce duck curve effect from PV penetration.  (3) Issues to be solved:(a) Government policy, law or regulations, grid code and road map need be defined. (b) Power/data/business flows among stakeholders need be clarified.</p>
<p>Technology: EV</p> <p>(1) Reason: Promotion of electrification of vehicles toward the realization of a low-carbon society  (2) Technical items:  (3) Issues to be solved: Miniaturization and cost reduction of chargeable/discharging equipment</p>

**What is your Policy for coping with social demands in the field of Strategic Technology Management ?**

<ul style="list-style-type: none"> <li>We will anticipate changes in the times and constantly incorporate new technologies and knowledge in order to lead to issues for the realization of a sustainable society, expansion of business areas, and cost reduction.</li> </ul>
<ul style="list-style-type: none"> <li>The digitalization is needed more and more in the next generation.</li> </ul>
<ul style="list-style-type: none"> <li>By utilizing AI, etc., to promote automation, labour saving, and paperless operations of various operations, we will improve efficiency and quality, and improve productivity. Specifically, we are aiming for digitization of monitoring and control and diagnostic technology utilizing AI. For this reason, we are working on the construction of digital infrastructure, the development of AI technology, and the development of human resources who analyse and utilize them.</li> </ul>
<ul style="list-style-type: none"> <li>It is important to ensure information security for the safe and stable supply of electric power and the protection of personal information held. As the threat of cyber-attacks on critical infrastructure that supports society increases, it is necessary to develop server security countermeasure technology that can respond to cyber-attack countermeasures, strengthening monitoring systems and virus countermeasures.</li> </ul>

<ul style="list-style-type: none"> <li>• New energy vehicles are developing quickly, but the number of charging stations and hydro-generation stations is insufficient. It is necessary to scientifically plan the urban layout, improve supporting policies, encourage business model innovation, accelerate the development of intelligent service platform and improve user experience.</li> </ul>
<p>In a deregulated market, three accelerators are necessary for continuous upgrading of technological solutions and invest, with clients for delivering infrastructures ‘as a service’:</p> <ul style="list-style-type: none"> <li>- Digital to strengthen the technical component of offers</li> <li>- Consulting to help the largest global companies to build their zero-carbon transition</li> <li>- Financing to leverage our impact on customers by setting up financial partnerships.</li> </ul>
<ul style="list-style-type: none"> <li>• As electric vehicles become an increasingly large proportion of the overall fleet (they already are beginning to replace ICE-powered vehicles), digital energy management will be critical to controlling the flow of energy from the grid to the vehicles during charging and from the vehicles to the grid (vehicle batteries as ‘storage’ for excess capacity). Consumers will expect their electric vehicles to behave much like the ICE vehicles to which they are accustomed. They will want them to take on energy quickly (as they do now when they are fueled at a gas pump), and they will want them available on demand 24/7. Unless/until there is major social adaptation, consumers will not accept the inconvenience of extended charging times or limited access to charging resources.</li> </ul>
<ul style="list-style-type: none"> <li>• Resiliency and flexibility of assets should be primary focus of management strategies with respect to new technologies development and market penetration. Technology innovation regarding digitalization, automated operation and control will allow higher implementation of clean technologies while providing more active and predictable power demand.</li> <li>• Improved monitoring of assets allows better control and decision-making regarding maintenance and operation control. Preventive maintenance and automatized equipment control will be more efficient with implementation such technologies.</li> <li>• Integration of power generation with other sectors will allow higher flexibility in power generation and automatized control. However, IoT and cyber security plays a vital role in implementing these new technologies which interconnects power generation and consumption. Major attention should be focused on cyber security to make these technologies robust and reliable.</li> </ul>
<ul style="list-style-type: none"> <li>• To reduce investment cost in infrastructure and operation cost of the electricity industry Digitalisation has a fundamental role.</li> <li>• Deregulation creates the competitive environment necessary for innovation</li> </ul>
<ul style="list-style-type: none"> <li>• We will make efforts using digital technology to evolve the energy service business, co-create a sustainable community, and strengthen the management base.</li> <li>• Achieve both stable supply and cost reduction by improving the efficiency and sophistication of equipment maintenance and work operations.</li> <li>• Promote the sophistication of network technology with the aim of popularizing renewable energy and efficient facility operation.</li> <li>• Create a business that utilizes network-related technologies and assets</li> <li>• Seriously address local and social issues and create new businesses and services that lead to richer, more comfortable lives and economic activities.</li> <li>• Efforts related to ‘ICT services’, ‘urban development, community development’, and ‘infrastructure services’ to solve local and social issues</li> <li>• Securing information security and pursuing safety and security even as the use of IoT and AI spreads</li> </ul>
<ul style="list-style-type: none"> <li>• Ability to integrate innovations in many fields to improve operation and management of the grid and customer and community integration. Agile methods, moving from demonstrations to deployment, integration of new technologies with existing practices, coordination with startup community.</li> <li>• Use of IoT and the Internet for system situational awareness, digital twin technology development, artificial intelligence, customer and community integration.</li> <li>• Advanced market approaches that integrate conventional market concepts with peer-to-peer trading and other advanced approaches to integrate widespread distributed resources and demand side technologies. These approaches need to consider non wires alternatives for system investment.</li> <li>• Resiliency approaches that integrate customer and community solutions with investments in the grid.</li> <li>• Use of augmented reality, advanced training concepts, artificial intelligence and other approaches to enhance the effectiveness of all elements of the work force – planning, operations, maintenance, customer engagement, etc.</li> </ul>

<ul style="list-style-type: none"> <li>• Integration of customer services as an integral part of overall utility operation – energy efficiency, energy management, resiliency, outage management, decarbonisation, etc.</li> </ul>
<ul style="list-style-type: none"> <li>• Digitization is not a specific business field within RWE, but is seen as a measure for operational improvement.</li> <li>• Cyber security is a very important topic especially for large power generators in order to keep the power plant operation protected from cyber attacks and therefore stable and reliable.</li> </ul>
<ul style="list-style-type: none"> <li>• We will actively incorporate new technologies such as AI and IoT to reduce costs, improve productivity, and create new services in the electric power business.</li> <li>• The challenge is to secure and develop human resources to promote digitalization, as we have started the above-mentioned efforts late.</li> </ul>
<ul style="list-style-type: none"> <li>• From now on, it will be important to combine on-grid data via power infrastructure and off-grid data via IoT terminals to provide new value that meets the challenges of living, industry, and communities together with energy services. We believe that the progress of DX is an opportunity to dramatically improve the quality and speed of these services.</li> </ul>
<ul style="list-style-type: none"> <li>• With the Covid-19 pandemic, technology and innovation initiatives, particularly Cybersecurity measures, will prove to be more essential as we spend more time online (e.g., virtual meetings, remote-working set-up, online payment/transactions, etc.) due to physical distancing and other health protocols. The business disruption caused by the pandemic has created several cybersecurity risks that need to be addressed by the utilities. In general, Meralco continues to embark on its digital transformation programme across the enterprise which includes deployment or upgrade of its major systems to complement its existing systems.</li> </ul> <p>Safety is the top priority for keeping the workforce up and well and for ‘keeping the lights on’ to support the government and the front-liners to overcome the Covid-19 pandemic. An effective Business Continuity Plans is a necessity to curb spread of covid-19 in the workplace. Some of the initiatives are:</p> <ul style="list-style-type: none"> <li>- Provision of PPEs, vitamins, hygiene kits to employees and use of health declaration and contact tracing apps for the monitoring of health and wellness of employees.</li> <li>- Implementation of physical distancing and temperature scanning in the workplace.</li> <li>- Regular workplace disinfection.</li> </ul> <p>Conduct of roadshows and info dissemination on health protocols.</p>
<ul style="list-style-type: none"> <li>• Accelerating spread of storage batteries and EVs in response to changes in the business environment such as a decrease in demand due to the declining population in our area, full liberalization of electricity retailing, and structural changes in supply and demand and equipment due to the expansion of the introduction of renewable energy. In addition to technological innovation toward the future, I think it is necessary to integrate digital technologies such as IoT.</li> <li>• Specifically, with the increase in players due to deregulation and the creation of new markets, in more complicated supply and demand operations, through actively promoting AI technology to optimize the combination of enormous variables and aim maximize profit.</li> </ul>
<ul style="list-style-type: none"> <li>• This is a broad topic; however, an area of interest for us here is the notion of ‘hydrogen accreditation’. There is lots of interest in a range of different hydrogen projects – based on coal, gas, wind, solar PV, and more. From a ‘management’ perspective there is the expectation that we are able to ‘certify’ hydrogen based on some criteria – whether it be the energy source (such as renewable, gas with CCS, etc.) or its carbon intensity at a specific point in the value chain.</li> </ul>
<ul style="list-style-type: none"> <li>• The major energy policy in A18 is all about the promotion of green power and termination of nuclear power. The overall power system will be more unstable (caused by the increasing amount of intermittent renewable energy and decreasing amount of nuclear and fossil power plants) if we do not do anything correspondingly. To ease the problem of the power system, demand side resource may be a key to help.</li> <li>• For example, the ADR (auto demand response) and other responsive demand management measures can be timely resource for system operators to keep the frequency of the power system in an appropriate range when facing the instability of renewable energy. In addition, the VPP (virtual power plant) that integrates relatively small scaled renewable energy, storage, and demand response resource also has the potential to help the power system to be stable.</li> </ul>

<ul style="list-style-type: none"> <li>In our opinion, to achieve the goal of stable power system, the IRP (integrated resource planning) method for planning (operating), and the market mechanism (incentives) design are the most important items in the field of management.</li> </ul>
<ul style="list-style-type: none"> <li>To provide a new market-oriented solution to problems such as the shortage of deep peak shaving resources, we focus on using blockchain, new multi-party settlement trading platform and other tools to break through the key technologies of customer side flexible resource interactive operation and transaction-driven power grid system regulation. Combined with Chinese power system reform process, we explore market trading mechanism and business model suitable for customer side flexible resource interaction, to cultivate a new business environment for market-oriented trading of flexible resources on the customer side.</li> <li>With power customers and load aggregators as the centre, the design of transaction varieties and transaction service architecture is carried out to enhance the enthusiasm of user interaction and commercial stickiness.</li> <li>2. With the development of IOT and more intelligent terminals access to power grid, the cybersecurity of terminals is very important as risks could spread and threaten the security of power grid and cause blackout events. Thus, cybersecurity technology of terminals is quite necessary for IOT development and digitization industry.</li> </ul>
<ul style="list-style-type: none"> <li>Liberalisation of the market</li> <li>Setting up of the Independent market and system operator</li> <li>Poor ICT infrastructure, cost of ICT is extremely expensive locally, cybersecurity risks.</li> <li>Non-technical losses, non-payment</li> <li>Increased grid electricity due to changing generation mix. Low-cost base of electricity</li> </ul>
<ul style="list-style-type: none"> <li>Digital solutions are very important, for control, for customer interaction and more</li> </ul>
<b>What are the critical key drivers considered in your roadmapping approach?</b>
<b>IOT and Cyber-security</b>
Privacy
Construction of cyber security detection/defence technology and management system
AI, IoT, Cloud Computing, Edge computing, block chain
Cyber Security at A7 we have had no cases where the loss of production or operational shutdown occurred due to cyber attack.
Prosumers
Block chain, Specific Cryptography, Access detection
AI
Digital platforms for IoT integration across multiple stakeholders, Data management, artificial intelligence, new customer and community services, electric transportation integration
Assessment and validation of different and new solutions. Currently, no own R&D
Local 5G/blockchain/AI
Deep learning, blockchain
Data Warehousing, Cybersecurity enhancement on the Operation Technology (OT) systems/platforms
AI, big data analysis
AI deep learning, privacy, Block chain, Smart Industrial Safety, Cyber-security for control system
AI, user privacy, SCADA
Industrial control system security, cybersecurity based on deep learning, data security
<b>Resiliency and flexibility</b>
Emergency and disaster measures, adaptation for climate change
Securing power supply in an emergency, automatically detecting and grasping the damage status of equipment
Climate change risk management process as part of A7 Risk Management Framework.
Water management, black start technologies
LCP (life continuity plan), ANM (Active network management), DERMS (distributed energy resources management)
Forest conservation and disaster mitigation
Resiliency metrics, community and customer resiliency and flexibility engagement, cost benefit analysis, market structures incorporating flexibility and resiliency, IoT integration for resiliency and flexibility, dynamic rates, peer-to-peer
Consider using data for resilience
Emergency/disaster countermeasures
Earthquake countermeasures
Emergency and disaster measures, adaptation for climate change
RAMP (Risk Assessment and Management system for Power lifeline)
Emergency and disaster measures
Disaster Recovery, Disaster plan
<b>Generation and T/D facilities, equipment's</b>

<p>Technology: Power generation, power transmission and distribution equipment</p> <ol style="list-style-type: none"> <li>(1) Reason: To provide safe and stable power supply at a low price</li> <li>(2) Technical items: Advanced system protection devices, smart meters, drones and more.</li> <li>(3) Issues to be solved: Continuous technological development is required</li> </ol>
<b>Retail</b>
<p>Technology: retail</p> <ol style="list-style-type: none"> <li>(1) Reason: With the full liberalization of retail electricity, consumers need to continue to make choices.</li> <li>(2) Technical items: AI, storage batteries, electric vehicles</li> <li>(3) Issues to be solved: It is necessary to accumulate knowledge including technical aspects for monetization</li> </ol>
<p>Technology: Retail package Design</p> <ol style="list-style-type: none"> <li>(1) Reason: The energy end-users are usually insensitive and uncomfortable with respect to the highly dynamic or real-time pricing, due to the lack of competence to immediately respond to the price signal or little awareness of instantaneous opportunity.</li> <li>(2) Technical items: The design and analysis of the retail packages which include fixed rates; time-of-use (TOU); critical-peak pricing (CPP) and prediction-of-use (POU) tariff to rationalize energy consumption behaviour for the whole system cost. The optimized electricity retail package design reflects real-time price of the wholesale market.</li> <li>(3) Issues to be solved: The analysis method of the combination of the retail price modes to submit the optimized solution. The energy end-users can respond to the highly dynamic or real-time pricing offered by the utilities.</li> </ol>
<p>Technology: Headquarters</p> <ol style="list-style-type: none"> <li>(1) Reason: As the proportion of renewable energy increase, we have to take the demand side resources into account so as to ensure a stable and adequate supply of the power. That's why we need IRP models to consider both supply and demand side resources. In addition, IRP models helps to depict the possible energy roadmap under certain energy policy and it also helps to study the feasibility of certain energy policy.</li> <li>(2) Technical items: IRP models (Linear Programmemeing model)</li> <li>(3) Issues to be solved: IRP models are planning type models, and it may also be used for operating purpose if higher frequency data are provided and the uncertainty of renewable energy can be well considered.</li> </ol>
<p>Technology: Headquarters</p> <ol style="list-style-type: none"> <li>(1) Reason: TPC will become a holding company with two subsidiaries because of the electricity market reform policy. Organisation transformation and establishment of innovation centres to cope with the future challenges are necessary.</li> <li>(2) Technical items: Innovation management</li> <li>(3) Issues to be solved: Introducing new technology and digital transformation.</li> </ol>
<p>Technology: Electrification</p> <ol style="list-style-type: none"> <li>(1) Reason: Critical part of decarbonisation strategy and opportunity to apply optimization approaches to minimize investments needed</li> <li>(2) Technical items: technologies for electrification, integration and management approaches to minimize required investment</li> <li>(3) Issues to be solved: economics of electrification across many applications, platforms, management approaches, integration with planning and operations</li> </ol>
<p>Technology: business mode</p> <ol style="list-style-type: none"> <li>(1) Reason: PV/Storage product offerings from the utility</li> <li>(2) Technical items: change in business model, regulation, start-up organisation</li> <li>(3) Issues to be solved: regulation, commercialization, training for the new product offerings</li> </ol>
<b>New Frontier</b>
<p>Technology: New Frontier</p> <ol style="list-style-type: none"> <li>(7) Reason: In order to meet the social demand for low carbon, it is necessary to promote the electrification of heat sources that use fossil fuels.</li> <li>(8) Technical items: Industrial electrification</li> <li>(9) Issues to be solved: Development of low-cost heating method suitable for each field and application</li> </ol>
<p>Technology: New frontiers</p> <ol style="list-style-type: none"> <li>(1) Reason: Utilizing the technology and knowledge cultivated in agricultural electrification, which is our strength, we visualize</li> </ol>

<p>(explicit knowledge) the advanced production technology and know-how (tacit knowledge) obtained by utilizing advanced technology. So we can support existing farmers for productivity improvement (expansion of profits) and new entry of young people into agriculture, and to revitalize agriculture in our region</p> <p>(2) Technical items: Research on plant factories</p> <p>(3) Issues to be solved: Stable production and verification of high quality strawberry cultivation, cost reduction in terms of equipment and operation, popularization of agricultural electrification, provision of smart agricultural services</p>
<p>Technology: Innovation</p> <p>(1) Reason: Innovation strategy and organisation will be critical for integrating technologies from startups and other technology developers</p> <p>(2) Technical items: start-up and technology provider engagement, integration approaches, demonstrations, sandbox concepts, training, regulatory and market approaches</p> <p>(3) Issues to be solved: organisation, training, start-up engagement, tracking demonstrations, cost/benefit approaches, process integration</p>
<p><b>IOT and Cyber-security</b></p>
<p>Technology: IOT and Cyber-security</p> <p>(1) Reason: The safety of the electricity will be needed more and more.</p> <p>(2) Technical items: Security technology</p> <p>(3) Issues to be solved: Security software</p>
<p>Technology: Cyber-security</p> <p>(1) Reason: As digitalization proceeds and equipment and facilities are more interconnected and controlled automatically, cyber-security will play a key role to maintain these systems secure. This can be seen especially in hospitals, power plants and other major infrastructure.</p> <p>(2) Technical items: Digitalization</p> <p>(3) Issues to be solved: Systems security from external intervention.</p>
<p>Technology: IoT Integration</p> <p>(1) Reason: This impacts everything from assets to grid management to customer and community integration</p> <p>(2) Technical items: platforms for integration, data management, data security, artificial intelligence, service-based architecture</p> <p>(3) Issues to be solved: architecture, platforms, data management, data security, AI implementation, stakeholder coordination</p>
<p>Technology: Cybersecurity</p> <p>(1) Reason: With the development of IOT and more intelligent terminals access to power grid, the cybersecurity of terminals is very important as risks could spread and threaten the security of power grid and cause blackout events. Thus, cybersecurity technology of terminals is very necessary for IOT development and digitization industry.</p> <p>(2) Technical items: Intelligent terminals</p> <p>(3) Issues to be solved: As more and more intelligent terminals access the power grid, the exposed side of power grid becomes larger and risks are increasing. It is very important to conduct researches on how to protect terminals themselves and access security.</p>
<p>Technology: Cyber-security</p> <p>(1) Reason: Introduction of digitalization technologies introduces new areas of risk on the utility.</p> <p>(2) Technical items: skills</p> <p>(3) Issues to be solved: access to skilled staff</p>
<p>Technology: Cyber-security</p> <p>(1) Reason: Secure and reliable systems are of utmost importance</p> <p>(2) Technical items:</p> <p>(3) Issues to be solved:</p>
<p>Technology: Cyber security</p> <p>(1) Reason: We believe that it is the company's responsibility to ensure information security for the safe and stable supply of electricity and the protection of personal information we hold.</p> <p>(2) Technical items: Construction of cyber security detection/defence technology and management system</p> <p>(3) Issues to be solved: Cyber-attack methods are evolving day by day, and it is necessary to continue efforts to prepare for the</p>

occurrence of cyber-attacks, such as introducing new technical measures and strengthening monitoring and operation.
Technology: Block Chain  (1) Reason: Transparent and fair trading (2) Technical items: Block Chain (3) Issues to be solved: increase competition in the retail market and simplified market rules
Electric Transportation Integration Resiliency metrics, community and customer resiliency and flexibility engagement, cost benefit analysis, market structures incorporating flexibility and resiliency, IoT integration for resiliency and flexibility, dynamic rates, peer-to-peer
Technology: Data management in VPP business  (1) Reason: Although legal arrangements are required, it will be an important elemental technology in the interpersonal transaction of electric power, assuming that the spread of renewable energy will further progress and that the price of storage batteries will fall and spread to households. (2) Technical items: Blockchain (3) Issues to be solved: Blockchain is a technology under development, and knowledge on actual implementation such as information on technological progress and programming.
Technology: Remote management of power generation equipment, etc.  (1) Reason: Considering operational efficiency such as remote control and equipment monitoring, 5G, which enables real-time communication, is an important elemental technology. (2) Technical items: Use cases applicable to local 5G (VR, etc.) (3) Issues to be solved: Since 5G has just been introduced in Japan and the area is currently limited, information on use cases including private networks such as local 5G.
We are planning a digital system, possibly based on a blockchain type of approach, to be able to track hydrogen through the system and assign a carbon intensity to it according to its method of production, storage, distribution, etc.
Technology: 3D mapping (1) Reason: Simulation of power system in geographical environment is useful for disaster recovery plan. (2) Technical items: surveying and drawing (3) Issues to be solved: the quantity of assets and complexity of environment makes mapping a difficult task to complete.
Technology: Modelling (1) Reason: Simulation of state grid equipment helps with the illustration and asset management (2) Technical items: database management. (3) Issues to be solved: The storage and loading of the properties will influence the user experience because of its huge quantity.
<b>Resiliency and flexibility</b>
Technology: Resilience  (1) Reason: It is necessary to continue to take appropriate measures against the aging of electric power equipment and work on the efficient maintenance and operation of the equipment in order to deliver a stable power supply. (2) Technical items: Support for aging equipment and wide area of power network (3) Issues to be solved: Network construction using AI/IoT, disaster-resistant equipment construction
Technology: Resiliency and flexibility  (1) Reason: As it was mentioned before, resiliency and flexibility of the grid will be important with increasing high shares of renewable energy and increasing demand for power security. In times of crises or rapid economic development, black outs or local power supply intermittency might have a large consequence. (2) Technical items: High share of renewable energy (3) Issues to be solved: Developing energy grids and technologies to support energy supply.
<b>What are the key emerging technology identified from your roadmap in terms of (1) the reason, (2) technical items, (3) issues to be solved?</b>
<b>Generation and T/D facilities, equipment's</b>
Technology: Digital management of power generation equipment, etc.  (1) Reason: When aiming for more efficient operation of power generation equipment etc., it is assumed that the digital twin, which enables immediate simulation and is easy to visualize, will be an important elemental technology. (2) Technical items: Digital twin (3) Issues to be solved: Extraction of equipment if operational, required amount and type of data (use case)
<b>IOT and Cyber-security</b>

Technology: Blockchain

- (1) Reason: Blockchain can potentially have a medium impact on A7's customers seeking renewable energy certificates and peer-to-peer energy trading. While the former is a near-term opportunity, the necessity of blockchain for REC trading falls on a lack of trust in the system. The latter is a long-term opportunity depending heavily on an increase in consumer interest, which remains unlikely.
- (2) Technical items:
- (3) Issues to be solved: Despite the attractiveness of blockchain's features, applications remain highly experimental and in most cases lack any value proposition compared to incumbent data management approaches. Until enterprises establish a requirement for blockchain, several hurdles remain in identifying clear ROIs for deployment. In the near-term, expect to find blockchain deployment by early adopters in financial services and supply chain management. However, it will be several decades before other industries move beyond small pilot scale tests.


































Technology: IoT Integration

- (1) Reason: key to integrating sensors and intelligent devices across all levels of the system and society
- (2) Technical items: connection to millions of devices, data collection, data management, advanced optimization systems
- (3) Issues to be solved: communications, platforms, data, AI

Technology: Data security

- (1) Reason: With the development of big data, data nowadays has the characteristics of large volume, various types, low value density, and fast processing speed. How to manage the massive data security is the biggest challenge for the security of current data.
- (2) Technical items: data
- (3) Issues to be solved: Researches should be conducted on technologies of data desensitization, privacy protection and data leakage prevention. It is important to promote data security technologies under scenarios of industrial Internet data security, cloud platform data security, mobile terminal data security and data security transmission based on blockchain technology.

**Appendix 11: Qualitative table of categories, codes and frequencies for survey 2020/21**

	<b>Count</b>	<b>% Codes</b>	<b>Cases</b>	<b>% Cases</b>
 RQ1 Absorptive capacity				
 Business integration	2	0,8%	1	100,0%
 Multidisciplinary	1	0,4%	1	100,0%
 Technology diffusion	21	8,9%	1	100,0%
 CRQ2 ritical elements of a TRM framework				
 Benefit realisation	2	0,8%	1	100,0%
 Customer understanding	7	3,0%	1	100,0%
 Disciplined planning	3	1,3%	1	100,0%
 Organisational support				
 Technology resilience	27	11,4%	1	100,0%
 Technology application	12	5,1%	1	100,0%
 World view	3	1,3%	1	100,0%
 RQ3 Organisational process obstacles				
 Focus on revenue only	5	2,1%	1	100,0%
 Lack of a robust risk analysis	1	0,4%	1	100,0%
 Lack of disciplined execution				
 Lack of organisational support	2	0,8%	1	100,0%
 Lacking ecosystem understanding	1	0,4%	1	100,0%
 Operational perspective	12	5,1%	1	100,0%
 Political interference	2	0,8%	1	100,0%
 Shareholder first				
 Short-term strategic focus	3	1,3%	1	100,0%
 Sponser influence				
 Poor MRE	1	0,4%	1	100,0%
 RQ4 Critical constructs				
 Agility	8	3,4%	1	100,0%
 Climate change	38	16,0%	1	100,0%
 Organisational resilience	28	11,8%	1	100,0%
 Ecosystem understanding	17	7,2%	1	100,0%
 Environmental appreciation	12	5,1%	1	100,0%
 Political astuteness	9	3,8%	1	100,0%
 Social conscious	13	5,5%	1	100,0%
 Systems thinking (holism)	7	3,0%	1	100,0%