FORESIGHT-BASED POLICY DEVELOPMENT IN THE DEFENSE AND AEROSPACE INDUSTRY: THE CASE OF HONEYCOMB MATERIAL TECHNOLOGY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

GÜL BEYZA KOCAMIŞ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF SCIENCE AND TECHNOLOGY POLICY STUDIES

SEPTEMBER 2025

Approval of the thesis:

FORESIGHT-BASED POLICY DEVELOPMENT IN THE DEFENSE AND AEROSPACE INDUSTRY: THE CASE OF HONEYCOMB MATERIAL TECHNOLOGY

submitted by **GÜL BEYZA KOCAMIŞ** in partial fulfillment of the requirements for the degree of **Master of Science in Science and Technology Policy Studies, the Graduate School of Social Sciences of Middle East Technical University** by,

Prof. Dr. Sadettin KİRAZCI
Dean
Graduate School of Social Sciences _____

Prof. Dr. Mehmet Teoman PAMUKÇU
Head of Department
Department of Science and Technology Policy Studies _____

Prof. Dr. Mehmet Teoman PAMUKÇU
Supervisor
Department of Science and Technology Policy Studies _____

Dr. Cemal Berk OĞUZSOY
Co-Supervisor
C & O Consultancy and Software Services _____

Examining Committee Members:

Assoc. Prof. Dr. Arsev Umur AYDINOĞLU (Head of the Examining Committee)

Middle East Technical University
Department of Science and Technology Policy Studies _____

Prof. Dr. Mehmet Teoman PAMUKÇU (Supervisor)
Middle East Technical University
Department of Science and Technology Policy Studies _____

Prof. Dr. Elif ÇEPNİ
Karabük University
Department of Business Administration _____

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Gül Beyza KOCAMIŞ

Signature:

ABSTRACT

FORESIGHT-BASED POLICY DEVELOPMENT IN THE DEFENSE AND AEROSPACE INDUSTRY: THE CASE OF HONEYCOMB MATERIAL TECHNOLOGY

KOCAMIŞ, Gül Beyza
M.S., The Department of Science and Technology Policy Studies
Supervisor: Prof. Dr. Mehmet Teoman PAMUKÇU
Co-supervisor: Dr. Cemal Berk OĞUZSOY

September 2025, 158 pages

This thesis explores the future of honeycomb material technologies in the defense and aerospace sectors through a structured foresight framework. A mixed-methods research design integrating both qualitative and quantitative approaches was employed. Initially, a quantitative patent analysis was conducted as an input to validate the case selection, confirming the growing relevance of honeycomb structures in aerospace materials technology. This was followed by a Futures Wheel focus group, resulting in 24 foresight statements. These statements were evaluated based on their impact on the future, operational application areas, and dual-use potential, with the relative importance of each criterion determined using the Analytic Hierarchy Process (AHP). Final scores were calculated by combining participant ratings with these weights, ensuring that each score reflected both expert judgment and the strategic relevance of the criteria. Based on the top-ranked pathway, a second focus group was conducted using the Backcasting method, after

which a qualitative analysis was conducted to support the development of concrete policy recommendations.

This thesis contributes to the field by introducing a quantitative model for prioritizing pathways derived from Futures Wheel outputs, applying an integrated foresight framework that combines exploratory and normative approaches, and proposing a flexible scenario evaluation methodology suitable for various defense-related technological domains. Furthermore, it addresses a significant gap in Türkiye's defense planning ecosystem by offering a replicable and scalable foresight framework to support long-term decision-making.

Keywords: Foresight, Backcasting, Defense and Aerospace Technologies, Analytic Hierarchy Process (AHP), Scenario Planning

ÖZ

SAVUNMA VE HAVACILIK SANAYİSİNDE GELECEĞE YÖNELİK ÖNGÖRÜ TEMELLİ POLİTİKA GELİŞTİRME: BALPETEĞİ MALZEME TEKNOLOJİSİ ÖRNEĞİ

KOCAMIŞ, Gül Beyza
Yüksek Lisans, Bilim ve Teknoloji Politikası Çalışmaları Bölümü
Tez Yöneticisi: Prof. Dr. Mehmet Teoman PAMUKÇU
Ortak Tez Yöneticisi: Dr. Cemal Berk OĞUZSOY

Eylül 2025, 158 sayfa

Bu tez, savunma ve havacılık sektörlerinde bal peteği yapılı malzeme teknolojilerinin geleceğini yapılandırılmış bir öngörü süreci aracılığıyla incelemektedir. Hem nitel hem de nicel yaklaşımları bir araya getiren karma yöntemli bir araştırma tasarımı uygulanmıştır. İlk adımda, vaka seçimine girdi sağlamak amacıyla yapılan nicel patent analizi, bal peteği yapıların havacılık malzeme teknolojisindeki artan önemini doğrulamıştır. Ardından Futures Wheel (Gelecekler Çarkı) odak grup çalışması gerçekleştirilmiştir ve 24 öngörü ifadesi elde edilmiştir. Öngörü ifadeleri, geleceğe etki, operasyonel uygulama alanları ve çift kullanımlı potansiyeli olmak üzere üç kritere göre değerlendirilmiş; her bir kriterin göreli önemi Analitik Hiyerarşi Süreci (AHP) yöntemiyle belirlenmiştir. Nihai skorlar, katılımcı puanlarının bu ağırlıklarla birleştirilmesiyle hesaplanmış; her bir skorun hem uzman yargısını hem de stratejik öncelikleri yansıtması sağlanmıştır. En yüksek puanı alan gelecek patikasına yönelik Backcasting (Tersgörü) yöntemiyle gerçekleştirilen ikinci bir odak grup çalışması düzenlenmiş, nitel veri analizi yapılmış ve politika önerileri geliştirilmiştir.

Toplamda 16 politika önerisi üretilmiş, bunlar dört stratejik tema altında gruplanmış ve kısa, orta ve uzun vadeli zaman ufuklarına göre yapılandırılmıştır.

Bu tez, Futures Wheel çıktılarından ortaya çıkan gelecek patikalarını önceliklendirmeye yönelik nicel bir model sunarak, keşifsel ve normatif yaklaşımları birleştiren entegre bir öngörü çerçevesi uygulamakta ve çeşitli savunma odaklı teknoloji alanlarına uygun esnek bir senaryo değerlendirme yöntemi önermektedir. Ayrıca, Türkiye'nin savunma planlama ekosistemindeki önemli bir boşluğu ele alarak, uzun vadeli karar alma süreçlerini destekleyecek çoğaltılabilir ve ölçeklenebilir bir öngörü süreci sunmaktadır.

Anahtar Kelimeler: Öngörü, Tersgörü, Savunma ve Havacılık Teknolojileri, Analitik Hiyerarşi Süreci (AHP), Senaryo Planlaması

To all who are ready to work like bees, seeking ways to decide and to shape the future.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my thesis advisor, Prof. Dr. M. Teoman Pamukçu, and my co-advisor, Dr. Cemal Oğuzsoy, for their support, guidance, and insight throughout this research. Their expertise and encouragement have been instrumental in shaping my academic journey. I am also profoundly thankful to Assist. Prof. Dr. Arsev Umur Aydınoğlu for being a mentor who helped me discover what it truly means to be a researcher. His guidance pushed me to think deeper, write academically, and step confidently into academic spaces. He opened doors in my mind and in my academic path that I hadn't known existed, and for that I will always carry a deep appreciation. I am also grateful to him for serving as a member of my defense committee and for his thoughtful contributions during the process. I am especially grateful to Prof. Dr. Elif Çepni, not only for her role as a defense committee member but also for being a source of intellectual inspiration and personal encouragement. Her expertise in the field of foresight and her sincere, open-hearted support have deeply touched me and motivated me throughout my journey.

In addition, I am also thankful to all those at TEKPOL for their valuable support, friendship and contributions throughout this journey. While I cannot name everyone individually, their encouragement has been truly appreciated.

I am also thankful to my managers and colleagues at Turkish Aerospace for sharing their support, knowledge, and experience during the thesis process. Lastly, I am grateful to all the participants from various sectors who contributed to this research selflessly, expecting nothing in return. Their willingness to share insights has been invaluable to this study.

Above all, I am deeply grateful to my mother, Gülten Kocamış, my father, Carullah Kocamış, and my siblings, Rabia Nur Kocamış and Muhammed Emre Kocamış, for their support and love. Their belief in me has been my greatest strength, and I could

not have achieved this milestone without them. I am thankful from the bottom of my heart. Finally, here's to me, I want to thank myself for discovering passion, especially for research, and for showing up even through sleepless nights. And to the friends who stood by me in tough times: you know who you are. Having you around meant more than I can put into words.

TABLE OF CONTENTS

PLAGIARISM iii
ABSTRACT iv
ÖZ vi
DEDICATION viii
ACKNOWLEDGMENTS ix
TABLE OF CONTENTS xi
LIST OF TABLES xiii
LIST OF FIGURES xiv
CHAPTERS
1. INTRODUCTION 1
1.1. Significance Of The Thesis 5
1.2. Organization of The Thesis 8
2. LITERATURE REVIEW 10
2.1. Technology Foresight 10
2.1.1. Technology Foresight Methodologies 13
2.2. Materials Science 14
2.2.1. Materials Science in Defense Industries 16
2.2.2. Honeycomb Materials Technology 20
2.3. Materials Technology Foresight Studies 27
3. THEORETICAL BACKGROUND AND METHODOLOGY 32
3.1. Foresight Methods 32
3.1.1. Futures Wheel 33
3.1.2. Backcasting 38
3.2. Quantitative Methods 40
3.2.1. Patent Analysis 40
3.2.2. Multi-Criteria Decision Making (MCDM) 42
3.2.2.1. AHP 47
3.3. Qualitative Methods 51

3.4. Research Design 54
3.4.1. Patent Analysis for Case Validation 56
3.4.2. Designing a Multi-Criteria Evaluation Framework 58
3.4.3. Futures Wheel Scoring and Path Evaluation Framework 61
3.4.3.1. Node Scoring Formula 63
3.4.3.2. Temporal Weighting 64
3.4.4. Futures Wheel Focus Group (Implementation Phase) 65
3.4.5. Backcasting Focus Group 72
4. FINDINGS & DISCUSSION 76
4.1. Futures Wheel Focus Group Analysis 76
4.1.1. Evaluation and Aggregation of Criteria Weights 77
4.1.2. Futures Wheel Prioritization Outcomes and Methodological Discussion 80
4.1.2.1. Prioritization 80
4.1.2.2. Methodological insights 87
4.2. Backcasting Focus Group Analysis 90
4.2.1. Enhancing Honeycomb Materials Technology 92
4.2.2. Bridging Research and Application 94
4.2.3. Indigenous Capability Development 97
4.2.4. Advancing Sustainability through Lightweight 101
5. CONCLUSION AND POLICY RECOMMENDATIONS 104
5.1. Overview Of The Research Process And Main Outcomes 104
5.2. Policy Recommendations 107
5.3. Limitations And Suggestions For Future Research 114
REFERENCES 119
APPENDICES
A. NOTATION SUMMARY FOR AHP METHOD 141
B. METU HUMAN SUBJECTS ETHICS COMMITTEE APPROVAL LETTER 142
C. INTERVIEW GUIDE FOR BACKCASTING FOCUS GROUP 143
D. BACKCASTING CANVAS TEMPLATE (MIRO BOARD) 144
E. FINAL VERSION OF BACKCASTING CANVAS (MIRO BOARD) 145
F. TURKISH SUMMARY / TÜRKÇE ÖZET 146
G. THESIS PERMISSION FORM / TEZ İZİN FORMU 158

LIST OF TABLES

Table 1. Characteristics of Technology Foresight and Strategic Foresight 12
Table 2. Literature Review Summary on Materials for Defense and Aerospace Industries 18
Table 3. Glossary of Key Technical Terms in Honeycomb Materials Technology .. 25
Table 4. Overview of Selected MCDM Methods in Foresight Applications 44
Table 5. The Fundamental Scale for AHP Pairwise Comparisons 48
Table 6. Average Random Consistency Index (RI) Based on Matrix Order (Criteria number) (n) 50
Table 7. Scoring Scale for Criteria 61
Table 8. Futures Wheel Participant Profile Overview 66
Table 9. Backcasting Focus Group Participants 72
Table 10. Individual and Aggregated Weights for Criteria 79
Table 11. Prioritized Future Paths Based on Temporal Weighted Path Scores 82
Table 12. Policy Proposals for the Short Term (0–5 Years) in Türkiye 110
Table 13. Policy Proposals for the Medium Term (5-10 Years) in Türkiye 111
Table 14. Policy Proposals for the Long Term (10+ Years) in Türkiye 113

LIST OF FIGURES

Figure 1. Basic concept of honeycomb with hexagonal configuration and natural beehive. 20
Figure 2. Construction of a honeycomb core sandwich panel 23
Figure 3. Futures Wheel 34
Figure 4. Research Design and Methodological Flow 55
Figure 5. Top IPC Classifications in Aerospace Materials Patents (Last 10 Years) 57
Figure 6. Long-Term Patent Trends in Advanced Structural Materials (1981–2023) 58
Figure 7. Interface for Pairwise Comparison of Evaluation Criteria (AHP Input Screen) 68
Figure 8. Central Node Interface 68
Figure 9. Participant Interface for Entering and Rating a Foresight Statement 69
Figure 10. Example Scenario Path Created through the Futures Wheel 71
Figure 11. Final interface of the web-based Futures Wheel platform. 78
Figure 12. Code System 91

CHAPTER 1

INTRODUCTION

The future of the defense and aerospace industry is directly influenced by advancements in materials technologies. As materials science evolves at a remarkable pace, it not only adapts to technological progress but also actively drives and enables it. This transformative role of materials is not a recent phenomenon but a recurring theme throughout history. From the early days of metallurgy to the rise of modern nanotechnology, the development of new materials has consistently shaped technological progress, particularly in military applications. The continuous innovation in materials science is driven by the need to develop materials with specific properties tailored for distinct applications (Rajput et al., 2024).

In the aerospace industry, where extreme conditions demand exceptional materials performance, these advancements become even more critical. The development of new materials technologies is vital for maintaining a competitive edge in the global aerospace industry (Babus et al., 2004). While materials science is a critical factor in advancing aerospace systems, it is important to consider the broader context of technological innovation. The integration of artificial intelligence, cyber warfare, and unmanned systems alongside advanced materials is transforming military capabilities and strategies. The synergy between cutting-edge materials and emerging defense technologies offers a comprehensive approach to strengthening military systems and addressing the complexities of future threats (Patil et al., 2024).

Given this synergy and the rapid pace of materials advancements, it becomes crucial to adopt future-ready decisions that enable long-term planning and informed policymaking. As materials innovations continue to develop, their implications for defense capabilities and technological landscapes become more profound and

interdependent. Understanding and preparing for these future developments in materials science is essential for industry leaders, governments, and academia, allowing them to shape policies, allocate resources effectively, and secure sustained global competitiveness. This proactive approach will ensure that the defense and aerospace industry remain resilient and adaptable as new technologies and challenges continue to emerge (Sarjito, 2024).

Technology foresight provides a systematic framework for proactive approach, enables to identify emerging technologies and key research areas with the potential for significant future impact (Martin, 1995). Rather than merely predicting the future, foresight serves as a critical tool for shaping it by aligning technological developments with strategic priorities and ensuring sustained competitiveness in an era of rapid innovation (Romanowski & Nadolny, 2018). The foresight in materials science can lead to economic benefits by identifying trends and opportunities for innovation, ultimately strengthening national defense capabilities and competitiveness (Farcal et al., 2023).

In this context, selecting and analyzing specific materials technology becomes essential to demonstrate how foresight can inform future decisions in defense and aerospace sectors. This thesis investigates honeycomb materials as a concrete case for examining the future-oriented role of materials technology in defense and aerospace. The decision to center the study on these materials was informed by a review of recent literature and supported by a patent analysis, which indicated their growing strategic relevance in advanced materials. Based on a geometric pattern found in nature and bio-inspired by the efficient architecture of beehives, honeycomb materials are known for combining strength with lightness (Qi et al., 2021), which are both especially vital qualities in aerospace, where reducing weight is among the most critical design requirements. In addition to enabling lightweight structures, they also allow for enhanced functionality, making them one of the most strategically valuable material systems in these fields (Bitzer, 1997; Singh et al., 2024). As materials technology, they represent the broader goal of shaping and adapting materials to meet specific needs. Their widespread and long-standing use in defense systems, and their continued

development for future platforms, highlight their strategic importance and the need to include them in forward-looking policy and planning efforts (SSB, 2024).

To examine the future potential and strategic implications of honeycomb materials, this thesis employs specific foresight methodologies designed to explore alternative technological developments and inform future policy recommendations. For this purpose, the study utilizes two foresight methods, known as Futures Wheel and Backcasting. The Futures Wheel method facilitates the visualization of potential consequences arising from a specific event or technological shift, allowing for the exploration of both direct and indirect outcomes (Glenn, 2009). These outcomes help construct alternative future paths, making the method a valuable tool within the broader scenario planning process, which involves building structured narratives to explore uncertainties and support strategic decision-making in the face of multiple possible futures (Bradfield et al., 2005; Tran & Daim, 2008). Meanwhile, Backcasting begins with the identification of a desired future state and works backward to outline the necessary steps and actions required to achieve that future (Bengston et al., 2020).

Building upon the conceptual and methodological background outlined above, this thesis investigates the future role of honeycomb materials technologies within the defense and aerospace sectors. To guide this inquiry, the research is structured around the following two central research questions:

i. What is the prioritized future of honeycomb materials technologies in the defense and aerospace industries?
ii. What policies are needed to enable the realization of this prioritized future?

These questions form the basis of the study, which adopts a mixed-methods approach that integrates both quantitative and qualitative research techniques. In the context of this thesis, the term prioritized future refers to the most strategically desirable and policy-relevant future, identified through a structured expert evaluation process. This prioritization is based on three key criteria: the transformative impact of the technology, its operational applicability across defense platforms, and its dual-use potential for both military and civilian sectors.

In the initial step, the study applied a quantitative methodology through patent analysis to identify and validate honeycomb materials as a case study, confirming their relevance and future potential as a transformative materials technology in the defense and aerospace sectors.

In the initial step, rather than serving as a central analysis, the study applied a quantitative methodology through patent analysis as an input for case validation. This step was intended to empirically confirm that honeycomb materials represent an active and strategically relevant technology, specifically within the defense and aerospace sectors, thereby justifying their selection as the case study for subsequent foresight exercises. Subsequently, the first focus group, based on the Futures Wheel method, examined future scenarios ranging from the short to the long term, while exploring the potential impacts of honeycomb materials technology on air and space platforms within the defense industry over time. The focus group was composed of ten experts from industry, government, and academia, selected for their specialization in defense technologies, aerospace materials, and innovation policy. This stage combined qualitative analysis with a prioritization process, where participants responded to predefined criteria designed in advance.

The study conducted prioritization using the Analytic Hierarchy Process (AHP) method, based on three main criteria: impact on the future, operational application areas, and dual-use potential. Each criterion was evaluated, and each foresight statement in the Futures Wheel was scored by the participants according to these criteria. The data used for this assessment were collected during the first focus group. Participants provided individual ratings for each foresight statement across the three criteria and completed a pairwise comparison to determine the relative importance of the criteria for AHP weighting. AHP was applied to calculate the weights of the criteria. Final prioritization of future path was performed by calculating the scores of each foresight statement with the corresponding AHP-derived criterion weights and timeline weights. This allowed for the calculation of an overall score for each path in the Futures Wheel, revealing the most prioritized future. In the second focus group, the study applied qualitative analysis using a Backcasting-based format, in which participants worked backward from the prioritized future to identify the actions and

conditions required to achieve it, starting from long-term strategies and progressing toward short-term steps. The discussion focused on exploring the policy recommendations necessary for realizing this future, with particular attention to the alignment of government, industry, and academia within the Triple Helix model. This session included seven participants, six returning individuals from the previous Futures Wheel focus group and one new expert with a background in patent analysis and materials science, ensuring both continuity and a degree of disciplinary diversity.

Building upon the methodologies discussed, this thesis proposes an approach that prioritizes the futures identified by participants through Futures Wheel tool and applies it to the case of honeycomb materials technology in a defense related context. This approach incorporates a unique set of criteria, enabling the systematic evaluation and prioritization of potential future pathways derived from the Futures Wheel outcomes. The methodology presented is designed to be adaptable, allowing any researcher or practitioner to apply this tool to defense topics and refine the resulting future scenarios, paving the way for the subsequent Backcasting step. While this thesis specifically showcases a case study of materials science advancements in defense, the proposed methodology is applicable to various other defense-related areas, providing a flexible framework for future explorations.

1.1. Significance Of The Thesis

This thesis offers three significant contributions to the field of foresight. First, it contributes to the establishment of systematic foresight practices in Türkiye, particularly in the defense and aerospace industry, and underscores the significance of this study in addressing that gap with the edge. Second, it tackles a major methodological challenge by proposing a way to prioritize among the multiple scenarios generated through the Futures Wheel, utilizing an integrated approach that combines qualitative input with criteria-based weighting. This supports more informed and transparent decision-making. Third, it offers a flexible and adaptable framework for scenario evaluation and prioritization while originally applied to a case study in materials science yet designed to be transferable to various other domains within the defense field.

The first contribution which consists of integrating of foresight into defense planning is crucial for anticipating disruptive trends and emerging threats. Without proactive foresight, national defense strategies risk becoming reactive and inadequate in addressing future challenges. For example, rapid advancements in synthetic biology and biotechnology are reshaping the biological threat landscape, and the inability to foresee such developments can significantly compromise strategic decision-making (Nelson et al., 2021). In addition, foresight is vital for the efficient allocation of defense resources. In its absence, decision-makers may misallocate funding, leading to inefficiencies, capability gaps, or critical vulnerabilities that undermine long-term security objectives (Katoch, 2006). Despite its strategic importance, foresight activities and methodologies remain underutilized in Türkiye, particularly within the defense sector. Although there are a few scholarly contributions focusing on foresight and modeling in specific domains such as mobile applications in the defense industry (Bilge, 2018), aerospace communication technologies (Yüksel, 2018), and cybersecurity (Çifçi, 2019), Türkiye still lacks an integrated strategic foresight mechanism across its defense ecosystem. This deficiency is particularly evident in areas such as the defense procurement cycle, which involves not only acquisition decisions but also long-term planning, prioritization, and coordination across institutions, all of which require strategic foresight to effectively anticipate future threats and technological changes (Mevlutoglu, 2017). Such limited engagement with foresight reflects a broader challenge observed in many developing countries, where structural and institutional constraints often hinder the effective integration of foresight tools into policy and planning frameworks. Dreyer and Stang (2013) conducted a comparative study of foresight practices in 22 countries and observed that such activities are predominantly concentrated in developed nations, often conducted at national or regional levels. In contrast, low- and middle-income countries tend to engage less with foresight, as they are preoccupied with more immediate concerns such as poverty, basic security, and resource scarcity. The authors argue that while many Western states use foresight as an active policy tool to navigate economic or geopolitical uncertainties, for developing countries foresight often serves just as a passive visioning exercise (Dreyer & Stang, 2013). Considering the growing importance of foresight in achieving strategic resilience and global competitiveness,

Türkiye's limited use of foresight in the defense sector reveals both a critical gap and a unique opportunity. By adopting foresight practices more systematically and embedding them into long term planning processes, Türkiye could enhance its capacity to anticipate long-term challenges, make more informed strategic decisions, and strengthen its position in the international defense arena. This thesis addresses that gap by introducing a structured and adaptable foresight methodology, offering both a practical tool and a concrete case study through the application of this approach to honeycomb material technologies, which are recognized for their importance in defense and aerospace. In doing so, it provides guidance for decision-makers in the Turkish defense sector to engage with future-ready decisions in a more systematic and effective manner.

The second contribution of that is relates to one of the key challenges in scenario planning: selecting and prioritizing the most relevant scenarios among the many alternatives generated, even though all scenarios hold value. Policymakers often struggle to choose one scenario among many others to base their backcasting processes on. Integrating scenario planning with Multi-Criteria Decision Analysis (MCDA) has been proposed to enhance decision support. However, applying this integrated approach in real-world contexts presents significant challenges (Montibeller et al., 2006). Although Montibeller et al. (2006) conducted scenario planning for short-term futures and explored these challenges through two case studies, they highlighted the need for further improvements in the framework to effectively address these issues. The inherent uncertainty in predicting future conditions complicates the selection of a single preferred scenario (Bibri & Krogstie, 2019). Furthermore, as the number of potential scenarios can grow exponentially, managing and prioritizing them effectively becomes increasingly challenging. In light of this complexity, it is essential to adopt a structured approach to scenario development and evaluation (McBurney & Parsons, 2001). In addition, the dynamic nature of social, political, and environmental changes introduces further layers of uncertainty, making it difficult to predict which future will yield the most favorable outcomes (Wiebe et al., 2018). Selecting a single path for the future from a Futures Wheel refers to choosing one specific future trajectory, which is essentially the same as selecting a preferred future scenario. This process, therefore, requires a robust methodological framework capable of managing the complexity and

uncertainty inherent in the various scenarios. Such a framework should incorporate structured dialogues, carefully designed scenarios, and advanced analytical techniques (Wiebe et al., 2018). Integrating scenario planning with decision-making models is crucial to ensure more systematic and future-oriented policy outcomes (Çepni, 2019).

One major contribution of this thesis is in proposing a methodology that prioritizes and evaluates scenarios while establishing clear criteria for their assessment, thereby enhancing the practical applicability of the Futures Wheel tool for strategic decision-making.

The third contribution of this thesis consists of offering a flexible and adaptable framework for scenario evaluation and prioritization. While the methodology is demonstrated through a case study focused on specific material technology, it is designed to be transferable across a wide range of topics within the defense industry. The structured process to be presented, from the construction of the Futures Wheel to the development of prioritization criteria, can be applied to other defense-related technological domains. Researchers and practitioners who follow the step-by-step methodology suggested in this thesis will be equipped to systematically explore alternative futures, identify prioritized one, and effectively conduct backcasting to develop effective policies for the future based on the prioritized scenario. This adaptability significantly enhances the utility of the proposed approach for foresight-driven planning across the defense sector.

Finally, although this thesis primarily positions itself within the fields of foresight and policy studies, it also provides a complementary contribution to the materials science literature. By systematically examining the future potential of honeycomb materials and linking their technological properties with long-term strategic planning, the study highlights research and innovation areas that may guide future investigations in materials science. Rather than offering a technical deep dive, the thesis bridges policy foresight with materials-oriented perspectives, creating a complementary space for dialogue between technology policy and materials science.

1.2. Organization of The Thesis

The first chapter of this thesis, the Introduction, provides an overview of the research topic by outlining the thesis framework emphasizing its contributions to the field of foresight. It also presents the structure of the thesis and includes a clear statement of the research question, highlighting the problem the study aims to address.

Chapter 2, Literature Review, begins with an overview of technology foresight, including its definition, and key approaches. It then narrows its focus to materials science in the defense industry, presenting information related to honeycomb material technologies and the application of technology foresight to materials science.

Chapter 3, Theoretical Background and Methodology, details the mixed-methods approach employed in this thesis. It provides definitions and explanations of key techniques such as patent analysis, futures wheel, backcasting, and multicriteria decision-making, and discusses the relevance of these methods to the research.

Chapter 4, Findings and Discussion, presents the results of the patent analysis and the outcomes of the focus group and prioritization process through the futures wheel technique. It also includes a qualitative analysis of the findings, along with the results derived from the backcasting-based focus group.

Chapter 5, Policy Recommendations and Conclusion, offers policy recommendations based on the outcomes of the study. This chapter also revisits the research question, synthesizes the findings, and provides insights derived from the analysis. Additionally, it addresses the limitations of the study.

CHAPTER 2

LITERATURE REVIEW

This chapter is divided into two main sections. The first provides an overview of main foresight concepts, outlining its definition, key methodologies, and commonly used approaches. The second examines materials science and materials technology, with particular emphasis on honeycomb materials, the role of materials science in the defense industry, and the integration of technology foresight within the defense-oriented materials technology context.

2.1. Technology Foresight

In literature, technology foresight has been defined in various ways, each emphasizing different aspects of its multifaceted nature and applications.

One definition states technology foresight as “a process involved in systematically attempting to look into the longer-term future of science, technology, economy, and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits” (Martin, 1995). It is also presented as a tool for strategic planning and forecasting, helping organizations navigate technological challenges and threats by providing precise insights for strategy formation (Martin, 1996). Furthermore, it helps align visions, goals, and development paths in science, technology, and innovation (STI), particularly in rapidly changing environments (Kvasha & L. Musina, 2021).

In addition, technology foresight is characterized as a comprehensive approach that integrates the outcomes of three interconnected activities: futures, planning and networking (Miles, 2002) . The first is futures, conceptualized by (Miles, 2002) as an

activity, which involves examining emerging trends, exploring long-term developments, constructing alternative scenarios, and visions. The second is planning which is focused on strategic analysis and setting priorities. Lastly, the third activity is networking, which emphasizes the inclusion of diverse stakeholder groups such as policymakers, researchers, industry representatives, and civil society actors through structured collaboration. This activity plays a pivotal role in technology foresight by fostering the integration of multiple perspectives, enhancing the legitimacy and inclusiveness of the foresight process, and building collective intelligence among stakeholders actively involved in scenario development and priority setting. The active engagement of these stakeholders ensures that ensures that the foresight outcomes are more robust, inclusive, and reflective insights, thereby enriching the overall strategic planning and decision-making processes (Armanto, 2024). Together, these three activities form a cohesive framework for foresight practices (Miles, 2002). Synthesizing these perspectives, technology foresight can be understood as an interdisciplinary and methodical process that integrates diverse methodologies to identify key domains and prioritize investments and research. This approach supports the development of medium- to long-term strategies while optimizing resources across organizational, national, and international levels. This definition highlights the core of foresight by emphasizing its strategic and innovation-oriented dimensions (Yuksel & Cifci, 2017).

In addition to technology foresight, there is a distinct term in the literature known as strategic foresight, which is described as the process of building the ability to see the future by broadening visionary capabilities, which involves mapping systems, studying history, scanning the environment, and integrating insights from diverse stakeholders to enhance understanding and develop foresight with insight (Hines, 2008). This approach not only focuses on envisioning future possibilities but also aligns closely with strategic foresight's primary goal of helping organizations and policymakers anticipate future changes, so that they can implement both short-term actions and long-term strategies to mitigate undesirable impacts (Hamel et al., 2021). Moreover, in the context of policy-making, strategic foresight is used to future-proof decisions by grounding them in a longer-term perspective, thereby ensuring that policies are adaptable and considerate of future societal needs (Bóck & Kettemann,

2024). In addition, for businesses, strategic foresight serves as a micro-foundation of dynamic capabilities, which supports the continuous alignment of assets and resources to respond flexibly to uncertain environments (Mohammadi, 2023).

Table 1. Characteristics of Technology Foresight and Strategic Foresight

Aspect	**Technology Foresight**	**Strategic Foresight**
Definition	A process systematically exploring the longer-term future of science, technology, economy, and society to identify emerging technologies with economic and social benefits (Martin, 1995).	Building the ability to anticipate the future through broad visionary capabilities, integrating diverse insights from stakeholders (Hines, 2008).
Purpose	Helps organizations anticipate technological changes and navigate technological challenges by providing strategic insights (Martin, 1996).	Aims to anticipate future changes to implement both short-term actions and long-term strategies (Hamel et al., 2021).
Key Activities	Futures (exploring long-term possibilities), Planning (strategic analysis), networking (broadening participation and collaboration) (Miles, 2002).	Mapping systems, scanning the environment, integrating diverse stakeholder insights to create foresight with insight (Hines, 2008).

The key difference between technology foresight and strategic foresight lies in their focus and approach. Technology foresight may consider economic and societal dimensions (Martin, 1995), it typically places a stronger emphasis on identifying and assessing emerging technologies. Strategic foresight, by contrast, adopts a broader lens that systematically includes technological, economic, social, and political drivers of change (Linturi et al., 2022). Furthermore, technology foresight often uses quantitative methods and road-mapping, whereas strategic foresight relies more on qualitative scenario planning and trend analysis (Gentner et al., 2018; McGowan, 2022). Although technology foresight and strategic foresight are conceptually distinct, they exhibit

methodological and functional similarities, making them closely aligned in practical applications. Technology foresight primarily focuses on the identification and assessment of emerging technological trends, which can be integrated into the broader strategic foresight process to develop comprehensive strategies that consider multiple future scenarios. This integration is essential for organizations and governments to effectively navigate the complexities of future developments and ensure sustainable growth and innovation.

2.1.1. Technology Foresight Methodologies

Throughout the technology foresight process, a diverse array of methodologies is carefully employed to draw well-informed conclusions about the potential advancements and developments that may shape the future of technology. Technology foresight methodologies can be broadly classified into several categories based on their characteristics and applications.

These methodologies can group into exploratory and normative approaches, each serving different purposes and offering unique insights. Exploratory methods focus on uncovering possible futures based on current trends and data. These methods aim to explore potential developments without a predefined goal, allowing for a broad view of future possibilities. Common examples include trend extrapolation, where past and current trends are extended into the future, and scenario-based techniques which explore different possible scenarios to understand a range of potential outcomes (Surve, 2014). Scenario-based techniques constitute a substantial subset of exploratory foresight methodologies. These approaches assist organizations and policymakers in navigating complex and ambiguous futures by organizing diverse input into structured frameworks. Among these, scenario analysis and scenario planning are commonly used and often appear interchangeably in the literature. While they are closely related, scenario planning is generally more strategic in scope (Bradfield et al., 2005). As it depicts multiple future scenarios through structured narratives, helping organizations explore uncertainties and prepare for different possible developments. This makes it particularly valuable in the context of technology strategy development (Tran & Daim, 2008).

Normative methods begin with a desired future outcome and work backward to identify the necessary steps to achieve that future. These methods are goal-oriented, often employing techniques like backcasting, which involves mapping out the necessary actions to reach a specific future, and technology roadmapping, which outlines the path forward to realize long-term goals. Technology roadmapping is a structured visual framework to align technological capabilities with future goals, outlining what technologies are needed, when, and how they can be developed or implemented over time (Phaal et al., 2004). Therefore, while exploratory methods are used to anticipate multiple potential futures, normative methods are focused on achieving a specific, desired future outcome (Surve, 2014).

Various studies have linked scenario planning from exploratory and technology roadmapping from normative methods (Hussain et al., 2017; Phaal et al., 2004), with some proposing integrated applications of both (Saritas & Aylen, 2010). While scenario planning offers a flexible way to explore uncertain futures, roadmapping translates those insights into concrete pathways for action. Integrating the two requires thoughtful design, as they operate at different levels, strategic versus operational, but their combination is particularly powerful in guiding innovation, long-term planning, and policy formulation (Saritas & Aylen, 2010). In this context, the fusion of scenario planning and roadmapping not only enhances the capacity of organizations to systematically anticipate, interpret, and respond to future developments but also supports the development of evidence-based policy recommendations by linking future visions with actionable strategies (Cann, 2010; Philbin, 2013). This makes them valuable tools not only for corporate decision-making but also for informing Science, Technology, and Innovation (STI) policies.

2.2. Materials Science

Materials science is an interdisciplinary field that focuses on understanding the properties, structure, and performance of materials, and their applications across various scientific and engineering disciplines such as mechanical, electrical, and civil engineering (Wang et al., 2020). It investigates the relationship between the structure

of materials at atomic or molecular scales and their macroscopic properties, which is crucial for designing and fabricating advanced materials (Parinov et al., 2022).

Materials science often involves distinguishing between the basic properties of materials and the technological methods through which these materials are configured into functional forms. Recognizing this distinction helps clarify the different focuses within material-related research and development.

Material types refer to general classes of substances such as composites, polymers, metals, ceramics, and nanomaterials, which are defined by their intrinsic physical and chemical properties (Ashby & Johnson, 2003; Callister & Rethwisch, 2020). These types serve as the essential building blocks of materials science and provide the basis for performance-driven innovations across sectors including aerospace, biomedicine, and energy (Callister & Rethwisch, 2020; Lombardo & Wang, 2021).

Materials technology refers to the technological processes used to modify, enhance, and apply materials to meet specific functional requirements (Burte, 1995). Materials technology emphasizes the transformation and optimization of material properties such as strength, flexibility, thermal resistance, or weight through techniques like processing, alloying, surface treatment, or structuring. According to the Norwegian University of Science and Technology (NTNU) (2017), it is a broad discipline that begins with the use of raw materials and extends to shaping them into forms required for intended functions, Aarhus University (2023) further defines materials technology as a cross-disciplinary field that integrates materials and production technologies to improve and adapt existing material systems for new demands . From this perspective, materials technology serves as a functional engineering solution, responding to specific design and performance challenges by tailoring the physical properties and internal architectures of materials. Examples of materials technologies include the development of engineered foams, architectured materials, and other structurally focused systems. Engineered foams, such as polymeric or metallic foams, are created by introducing gas bubbles into a solid matrix, enhancing properties like energy absorption, thermal insulation, and lightweight performance through material structuring (Ashby, 2006). These foams represent materials technologies where

intrinsic material characteristics such as density and mechanical damping are systematically tailored for targeted applications like impact protection or thermal management. Architectured materials are materials in which the mechanical or functional performance is primarily governed by their internal geometry rather than by composition alone. These materials are deliberately designed with ordered structures such as cellular frameworks, or periodic patterns to achieve desired behaviors across multiple scales (Fleck et al., 2010). Honeycomb structures, as a subclass of architectured materials, leverage geometric arrangement to significantly improve the strength-to-weight ratio of metals, polymers, or composites without changing their fundamental chemistry (Bitzer, 1997).They demonstrate the critical role of internal geometry and spatial configuration in achieving high-performance material behavior (Qi et al., 2021). This reflects a broader shift in engineering and aerospace innovation, where functionality arises not only from what materials are made of, but from how they are constructed.

2.2.1. Materials Science in Defense Industries

Across various industries the defense and aerospace industry stand out as one where materials science plays a particularly critical role, with its innovative applications driving technological advancements, enhancing operational capabilities, and addressing complex challenges. The literature highlights the significant impact of composite materials and processes and nanomaterials in these industries. Table 2 summarizes the key materials, their functions, and the corresponding literature sources describing these developments.

Composite materials, including polymer and ceramic matrix composites, offer significant advantages in aerospace applications by combining increased strength, corrosion resistance, and stiffness, which enable the development of lighter, more durable airframes with superior aero-thermodynamic properties and operational reliability (Yıllıkçı & Findik, 2013). These materials, such as carbon fiber-reinforced polymers (CFRP), possess a high strength-to-weight ratio, offering both high strength and stiffness while maintaining a low density, which is crucial for reducing the overall weight of aerospace structures (Kesarwani, 2017). Moreover, hybrid composites,

which integrate metal fibers into CFRP, enhance damage tolerance and electrical conductivity, mitigating the brittle failure behavior typically seen in traditional CFRP (Hannemann, 2018). In addition, advances in self-healing composites, such as the development of microcapsule-based, vascular, and intrinsic healing mechanisms, contribute significantly to improved mechanical performance, durability, and structural integrity under harsh conditions. These technologies address the challenge of damage susceptibility in composite materials, offering the potential to autonomously repair damage, thus enhancing the safety and longevity of aerospace component (Raj et al., 2024). Furthermore, these multifunctional materials can also incorporate additional features like electrical conductivity and impact resistance, significantly enhancing the performance of aerospace systems (Williams, 2019)

The integration of sustainable biocomposites and the application of AI in materials design represent promising future directions for further improving composite materials in aerospace (Al-Mamun et al., 2024). However, challenges remain, such as cost reduction and the need for improved processing methods. The brittle nature of some composites and their susceptibility to specific types of damage necessitate ongoing research and development to fully exploit their potential in aerospace and defense systems (Zhou, 2021). In the future, improvements should focus on enhancing damage tolerance through the development of more resilient matrix materials, incorporating smart damage detection systems, and advancing self-repair technologies. By addressing these gaps, the full potential of composite materials can be harnessed to achieve safer, more reliable, and sustainable airframe designs.

Nanomaterials, such as carbon nanotubes and graphene, provide enhanced strength, lightweight properties, and high-temperature tolerance, reducing the weight of aerospace structures by up to 30% and improving fuel efficiency and performance Additionally, nano-ceramics and graphene-based composites offer high-temperature tolerance and wear resistance, making them crucial for aerospace components exposed to extreme conditions. Nanomaterials optimize fuel additives and enhance sensor performance, contributing to more efficient and reliable aerospace systems (Hu, 2024). In defense applications, carbon nanotubes are utilized in body armor and smart textiles, providing enhanced strength and flexibility. Nanomaterials are also used in

radar-absorbing structures and camouflage paints, improving stealth capabilities (Guo et al., 2023). Furthermore, nanostructured materials, like nanothermites, are being developed for more efficient and safer explosives and propellants (Comet et al., 2019). While the potential of nanomaterials in aerospace and defense is significant, there are challenges to be addressed, such as cost, processing difficulties, and the need for further research to fully realize their capabilities. The integration of nanomaterials into operational systems requires collaboration between materials scientists and industry experts to overcome these hurdles and ensure the safe and effective deployment of these advanced materials (Kamal, 2018). Continued development of polymer and ceramic nanocomposites is expected to provide better electromagnetic shielding and structural health monitoring capabilities (Rathod et al., 2017). However, integration challenges remain in scaling up production and seamlessly integrating these materials into existing systems (Samareh & Siochi, 2017). Table 2 provides a summary of the literature reviewed on materials used in the defense and aerospace industries, highlighting key advancements, applications, and related research trends.

Table 2. Literature Review Summary on Materials for Defense and Aerospace Industries

Material	**Function**	**Source**
Composite Materials	Strong, corrosion-resistant, lightweight airframes.	Yıllıkçı & Findik (2013)
Carbon Fiber-Reinforced Polymers (CFRP)	High strength-to-weight ratio, reduced structure weight.	Kesarwani (2017)
Hybrid Composites (CFRP with Metal Fibers)	Improved damage tolerance, electrical conductivity.	Hannemann (2018)
Self-Healing Composites	Autonomous repair, enhanced durability.	Raj et al. (2024)
Multifunctional Composites	Electrical conductivity, impact resistance.	Williams (2019)
Sustainable Biocomposites	Eco-friendly, sustainable materials.	Al-Mamun et al. (2024)

Table 2. (continued)

Nanomaterials (e.g., Carbon Nanotubes, Nano-Ceramics, Graphene)	Lightweight, fuel-efficient, high-temp tolerant structures. High-temp tolerance, wear resistance.	Hu (2024)
Nanomaterials	Enhanced armor, stealth via radar absorption.	Guo et al. (2023)
Nanostructured Materials (e.g., Nanothermites)	Efficient, safer explosives and propellants.	Comet et al. (2019)
Polymer and Ceramic Nanocomposites	Electromagnetic shielding, health monitoring.	Rathod et al. (2017)
Nanomaterials for Operational Systems	Safe, scalable integration.	Kamal (2018); Samareh & Siochi (2017)

While composite and nanomaterials have substantially enhanced the performance, multifunctionality, and resilience of aerospace and defense systems ,as shown in Table 2, recent studies increasingly emphasizes not only the material types but also the materials technologies and structural configurations in which these materials are implemented, highlighting a shift toward architectured materials as critical drivers of next-generation aerospace and defense applications (Benedetti et al., 2021; Kladovasilakis et al., 2022; Singh et al., 2024).

Among these honeycomb materials technology have emerged as one of the most predominant and widely adopted configurations, particularly in aerospace and defense applications (Acanfora et al., 2023; Ambekar et al., 2021; Farooq et al., 2017). Honeycomb materials technology come forward as critical components in next-generation material systems, primarily due to their superior energy absorption capabilities and mechanical efficiency under dynamic loading conditions (Castanie et al., 2020; Kamble, 2023). Honeycomb materials technology are also considered highly effective in meeting Size, Weight, and Power (SWaP) optimization requirements, offering high specific strength and stiffness while facilitating the integration of multifunctional properties such as thermal insulation, acoustic damping, and impact resistance (Aminanda et al., 2005).

In addition, extant literature highlights not only the intrinsic advantages of honeycomb architectures but also their widespread adoption in both experimental and operational platforms across aerospace and defense domains. National-level strategic documents, such as the *Composite Technologies Vision Report* by the Presidency of Defense Industries (SSB, 2024), explicitly emphasize honeycomb core-based technologies as a foundational element for achieving lightweight, durable, and multifunctional indigenous defense systems. This national perspective is echoed by multiple NASA technical reports, which explore the structural efficiency and energy absorption behavior of honeycomb sandwich panels under extreme mechanical and thermal conditions, including hypervelocity impacts and pressurization loads (Nettles et al., 2023; Rinker et al., 2013; Ryan et al., 2009).

2.2.2. Honeycomb Materials Technology

Honeycomb materials technology take their inspiration from the remarkable architecture of natural beehives, where honeybees construct highly efficient hexagonal cells for storing honey and pollen (Qi et al., 2021). As illustrated in Figure 1 this biological design has evolved over millions of years to achieve an optimal balance between strength and material efficiency. The mathematical foundation of this efficiency was confirmed by Hales in 2001, who proved that the hexagonal configuration maximizes enclosed area while minimizing construction material (Hales, 2001). This naturally optimized geometry has since become a model for engineered honeycomb materials used across a wide range of structural applications.

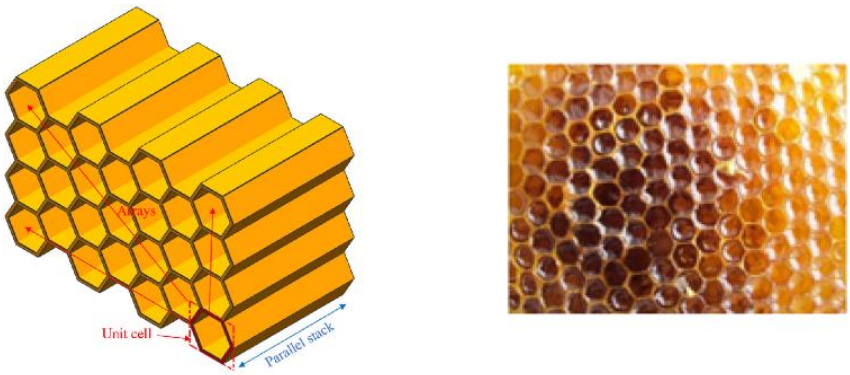


Figure 1. Basic concept of honeycomb with hexagonal configuration and natural beehive.

Source: Qi et al., 2021

To support this section, Table 3 presents a glossary of key technical terms referenced throughout the text to aid clarity and ensure terminological consistency.

While the hexagonal honeycomb is the most iconic and extensively studied form, recent advances in materials science have demonstrated that cellular materials inspired by nature can exhibit a wide range of geometries beyond simple hexagons (Zhang et al., 2020). These include triangular, square, kagome, re-entrant, and even stochastic or gradient-based architectures, each offering unique mechanical properties tailored to specific engineering demands (Qi et al., 2021).

These architected geometries are collectively referred to as *lattice structures*. A lattice is defined as a periodic or aperiodic network of interconnected struts or nodes that form the internal architecture of a material, often optimized for lightweight and high-strength performance (M.F Ashby, 2006).

The performance of lattice structures depends not only on their geometry but also on the manufacturing method, which influences material efficiency, structural integrity, and scalability (Bitzer, 1997). As such, various manufacturing techniques have been developed to accommodate different materials and lattice configurations (M.F Ashby, 2006).

Although the terms honeycomb and lattice are sometimes used interchangeably in the studies, it is important to distinguish between them. Lattice structures refer to a broad class of architected materials characterized by a network of interconnected struts or nodes, which may exhibit two- or three-dimensional periodicity. Honeycomb structures, by contrast, constitute a specific subset of lattice architectures, typically based on regular two-dimensional patterns such as hexagonal, triangular, or square cells. While all honeycombs are lattices, not all lattices adopt a honeycomb configuration.

The manufacturing method for the honeycomb structures varies based on the material used. Metallic honeycomb structures, typically made of aluminum or titanium alloys, are often produced through subtractive manufacturing as machining, or expansion

processes (Jaafar et al., 2021). Machining creates honeycomb structures by cutting material from a solid block, which is accurate but time-consuming and wasteful (Yu et al., 2019). Expansion bonds thin metal sheets to form the honeycomb, which is faster and more material-efficient, but adhesive bond strength is critical (Qi et al., 2021). Aluminum alloys and titanium alloys are common materials of honeycomb in aerospace applications (Bitzer, 1997). On the other hand, the most common used honeycomb structures are made from polymers and are commonly manufactured using additive manufacturing processes or by bonding pre-formed composite sheets (Miranda et al., 2021). These materials are increasingly viewed as the most promising alternatives to metallic lattices, not only due to their mechanical adaptability but especially because of their substantially lower weight (Tancogne-Dejean et al., 2018). Additive manufacturing has gained significant traction in recent years for producing such structures, particularly because it enables the creation of topologically optimized lattice geometries. These are designed through computational algorithms to place material only where it is structurally necessary, thereby reducing weight without compromising mechanical performance (Seharing et al., 2020). This process of selectively distributing material based on load paths and functional requirements is what defines topological optimization, making it a key approach in aerospace engineering where both strength and weight savings are paramount. Consequently, additive manufacturing has become the most common and versatile method for fabricating complex honeycomb and lattice structures in aerospace applications (Singh et al., 2024).

In engineering applications, honeycomb structures are rarely applied as independent structural elements. They are most frequently integrated as a core component within composite sandwich structures. A sandwich structure is a type of layered composite material system that combines mechanical efficiency with minimal weight (Callister & Rethwisch, 2020). It typically consists of three distinct layers: two high-strength outer layers referred to as face sheets, a low-density inner layer known as the core, and a thin adhesive layer that bonds them together. The core, positioned between the face sheets, increases the overall thickness and bending stiffness of the structure without significantly increasing its mass (Callister & Rethwisch, 2020; Kamble, 2023; M.F

Ashby, 2006; Q. Zhang et al., 2015). This structural configuration is shown in Figure 2.

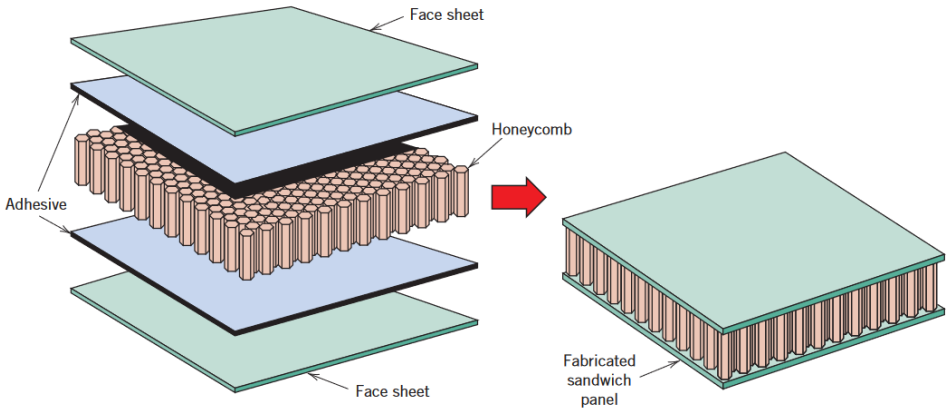


Figure 2. Construction of a honeycomb core sandwich panel

Source: Callister and Rethwisch (2020), originally adapted from ASM International (1987)

When honeycomb structures are employed in this context, it serves as the structural core, offering excellent stiffness-to-weight and strength-to-weight characteristics. This configuration is widely utilized in aerospace and defense industries, where structural performance must be balanced with strict weight limitations (Bitzer, 1997). Within this framework, the term *honeycomb* does not refer to the broader class of lattice geometries but specifically denotes the internal core structure found in what is technically identified as a honeycomb sandwich panel.

The materials commonly found in honeycomb cores can be grouped into two main types, known as thermosets and thermoplastics. These terms refer to how each material behaves when exposed to heat. Thermosets are materials that, once heated and shaped, become permanently hard and cannot be reshaped. This hardening process is called curing and results in a rigid structure. Epoxy and phenolic resins are typical examples of thermosets, often chosen when the application requires strength and resistance to high temperatures (Meza-Mendoza et al., 2018). The thermoplastics, on the other hand, can be softened by heat and reshaped multiple times without being damaged. Materials such as polypropylene and polyetherimide belong to this category (Callister & Rethwisch, 2020). Because thermoplastics are easier to recycle, better at absorbing

impact, and more compatible with automated manufacturing techniques, they are becoming more widely used in modern production (Zaaba et al., 2021).

This thesis positions honeycomb as a form of materials technology rather than simply a material type or structural geometry. This framing aligns with the definition of materials technology as the application of scientific and engineering principles to tailor material properties through structural design, processing methods, and functional integration (Ashby & Johnson, 2003). Honeycomb systems do not constitute a unique material in terms of chemical composition; instead, they represent a technologically mediated enhancement of base materials, such as metals, polymers, or composites, through geometric structuring. Their performance arises not from the intrinsic characteristics of the material alone, but from the deliberate engineering of internal architecture, manufacturing techniques, and application-specific configurations (Qi et al., 2021). In this respect, honeycomb structures exemplify a core principle of materials technology, achieving functional performance through the optimization of form rather than substance. As shown in prior studies, honeycomb configurations enable significant improvements in stiffness-to-weight and strength-to-weight ratios, making them indispensable in advanced structural systems such as aerospace sandwich panels (Bitzer, 1997; Zenkert, 1995). Accordingly, within the scope of this thesis, honeycomb is not treated as a static material type or just geometry but as a dynamic materials technology that reflects the convergence of geometry, manufacturing, and application in modern materials engineering.

Honeycomb materials technology have found their most prominent and widespread applications in the aerospace and defense industries, particularly within aircraft fuselages, wing panels, floorboards, radomes, and spacecraft components, where high stiffness-to-weight and strength-to-weight ratios are essential (Bitzer, 1997; Zenkert, 1995). Their use dates back to the mid-20th century, notably in military aircraft and space vehicles, where the demand for lightweight yet structurally robust materials first drove innovation in composite sandwich panels (Ma et al., 2021). Today, honeycomb cores remain a fundamental materials technology in advanced aerostructures and continue to evolve with the integration of thermoplastic matrices, additive manufacturing, and multifunctional design capabilities (Qi et al., 2021; Tancogne-

Dejean et al., 2018). Looking ahead, honeycomb structures are expected to play a critical role in next-generation aircraft, unmanned aerial systems, and reusable space systems, where the trade-off between performance, weight, and sustainability is more critical than ever (Singh et al., 2024). However, several technical challenges remain. These challenges include splitting layers under dynamic loading, moisture absorption in polymer-based cores, core crush, limitations in repairability, and the need for better damage detection techniques (Birman & Kardomateas, 2018). Addressing these issues requires further development in smart core materials, real-time structural health monitoring, and improved core–face bonding techniques, which represent active areas of ongoing research and technological advancement (Ma et al., 2021; Sobhy & Al Mukahal, 2023; H. Wang et al., 2019).

Given the technical nature of many of the concepts discussed above and considering that this thesis is addressed to readers without a background in materials engineering, with honeycomb presented as one case within a broader methodological context, a glossary of key terms related to honeycomb materials technology is provided in Table 3 to clarify the terminology used under that title.

Table 3. Glossary of Key Technical Terms in Honeycomb Materials Technology

Term	Definition	Source
Additive Manufacturing	A process that builds parts layer by layer from digital designs, allowing complex shapes and efficient material use.	Seharing et al. (2020)
Architectured Materials	Materials in which the mechanical or functional properties are primarily determined by their internal geometry rather than by chemical composition. These materials are deliberately designed with patterns or cellular structures to achieve specific performance outcomes.	Fleck et al. (2010)
Core Crush	A type of failure in sandwich panels where the lightweight core collapses under pressure or impact.	Birman & Kardomateas (2018)

Table 3. (continued)

Core–Face Bonding	The adhesion between the outer layers and the core in a sandwich panel, which is essential for transferring forces and maintaining strength.	Ma et al. (2021)
Honeycomb Core	A lightweight material with a regular, often hexagonal, cell structure used inside composite panels to increase stiffness without adding much weight.	Bitzer (1997)
Lattice Structure	A material made of a repeating network of struts or nodes, often used to form lightweight, high-performance architectures.	Ashby (2006)
Material Technology	The use of scientific and engineering methods to improve, adapt, or apply materials for specific functions or design needs.	Burte (1995)
Sandwich Panel	A three-layered structure made of two strong outer layers (face sheets) and a lightweight core, designed to combine strength and low weight.	Callister & Rethwisch (2020)
Smart Materials	Materials that can change their properties in response to environmental changes, such as temperature, pressure, or magnetic fields.	Sobhy & Al Mukahal (2023)
Structural Health Monitoring	The use of sensors and data analysis to monitor a structure's condition over time and detect possible damage.	Wang et al. (2019)
Thermoplastic	A plastic that softens when heated and can be reshaped multiple times without degrading its properties.	Callister & Rethwisch (2020)
Thermoset	A type of plastic that becomes hard and rigid after being heated once, and cannot be reshaped.	Meza-Mendoza et al. (2018)
Topological Optimization	A design method that determines the best placement of material based on performance needs, often used to reduce weight.	Qi et al. (2021)

2.3. Materials Technology Foresight Studies

Foresight studies are crucial across various sectors, and several studies specifically focus on foresighting new materials. One study explores scenario planning as a key method to explore the benefits of nanotechnology while managing associated risks. This research emphasizes the role of scenario planning in informing strategic decisions, addressing public concerns, and guiding leadership by examining the societal impacts of nanotechnology through hypothetical future scenarios (Farber & Lakhtakia, 2009). Another study examines more exploratory foresight by examining the potential technological advances in materials science over the next 50 years. It highlights themes such as sustainable cities, energy security, food and water security, and healthcare. This research discusses how materials science can contribute to solving these global challenges through the development of new materials and technologies (Miodownik, 2015). Furthermore, another study focuses on trend observation and employs exploratory methods, presenting its own ideas about the future of materials science. It looks beyond the last 50 years to envision advancements in various fields, including Energy, Transportation, Construction, Packaging, Recycling, and Healthcare (Apelian, 2007). In addition, some of the studies are more data-driven and evidence-based. One such study focuses on advanced nanomaterials and utilizes trend extrapolation techniques. This research applies data from SCOPUS, CORDIS, and PATSTAT databases to analyze trends, impacts, and implications. It develops indicators based on scientific publications, EU projects, patents, and funding programs (Farcal et al., 2023).

While these studies provide valuable insights, they often lack a methodological framework and tend to focus more broadly on speculative possibilities rather than offering concrete strategies for implementation. In contrast, recent foresight exercises conducted by organizations such as NATO, the European Union, and the Australian Government Department of Defense offer structured approaches to exploring the long-term implications of material advancements in defense industries. Through a detailed examination of these reports, valuable insights can be gained into emerging trends, key challenges, and potential opportunities shaping the future landscape of materials science in these strategic domains.

The NATO Science & Technology Trends 2023-2043 Report (Reding et al., 2023) identifies novel materials and manufacturing as one of the most disruptive technological fields. This research emphasizes the design and optimization of advanced materials and manufacturing techniques to address evolving defense needs. Key advancements in AI, quantum sciences, biotechnology, and hypersonics support this area, which prioritizes sustainability, rapid adaptation, on-demand production, and the resolution of SWaP-C (Size, Weight, Power, and Cost) challenges. Notable materials include two-dimensional materials such as graphene and graphyne, quantum nanomaterials, and advanced polymers, which exhibit unique properties like lightweight durability, eco-friendliness, and energy efficiency. The report highlights the transformative potential of two-dimensional materials, particularly in aerospace applications, where they enhance lightweight and strong composite structures critical for advanced technologies. Graphene, with its exceptional strength and conductivity, is a prime example, offering significant improvements in the performance and capabilities of aerospace systems. Research on 2D materials also extends to high-frequency electronics essential for radar and cooling systems, paving the way for more efficient and reliable aerospace technologies that provide critical advantages in defense applications. Additionally, nanomaterials facilitate breakthroughs in optics, acoustics, and electromagnetics, enhancing wave propagation control and enabling advanced technologies (Reding et al., 2023) .

Similarly, the EU Policy Lab, a unit within the European Commission's Joint Research Centre (JRC), conducted a participatory technology foresight exercise to identify and analyze emerging and disruptive materials technologies relevant to space, defense, and related civil industries (Farinha et al., 2023). The study highlights materials technology essential for advancing quantum communication technologies, such as those used for entangled photon production and nitrogen-vacancy (NV) centers in diamond, which are particularly significant for quantum sensing and communication. Integrated photonics materials are emphasized for their role in developing quantum communication systems and their implications for the EU's position in international standard settings. The report also underscores the criticality of silicon and semiconductor materials, particularly as silicon photonics and hybrid integration gain prominence, while noting challenges for start-ups in accessing these materials. Carbon

fiber composites, thermoset resins, and high-strength aluminum alloys are identified as crucial for future applications in space and defense. Additionally, lightweight radiation-resistant materials are highlighted for their potential in deep space exploration, and the scalable, low-cost manufacturing of nanosystems and materials for space applications is considered a key area for innovation (European Commission. Joint Research Centre., 2023; Farinha et al., 2023).

In Australia, The Department of Defense has conducted a comprehensive foresight study aimed at identifying observations, insights, and strategic opportunities in advanced materials and manufacturing, with a projection through 2040 (Burnett et al., 2018). This study underscores the critical importance of several materials technologies within the aerospace sector. Among these, composites and coatings are highlighted for their role in enhancing the performance and durability of aerospace components. Their ability to withstand extreme operational environments makes them indispensable for future advancements in aerospace systems. Another materials technology of focus is graphene-enhanced polymers, which contribute to the development of lighter yet stronger structures, essential for improving the efficiency and safety of aerospace technologies. These polymers offer the potential for significant weight reductions while maintaining or even increasing structural integrity, a key consideration for aerospace applications. Furthermore, the study emphasizes the transformative potential of nanomaterials, developed at the atomic and molecular levels. These materials exhibit unique properties—such as superior strength, conductivity, and thermal resistance—that can revolutionize aerospace technologies by enabling more advanced and efficient designs. The report aligns with the broader efforts of the Emerging Disruptive Technology Assessment Symposium (EDTAS) which is part of a government-led initiative focused on identifying and supporting the development of emerging technologies for future defense applications. The EDTAS series employs a systematic five-step methodology: Shaping & Insights Paper, Focused Technology Scan, Military Application and Implications, Capability Concept Capture, and Backcasting Validation. This structured approach ensures a thorough assessment of emerging technologies from conceptualization to strategic planning (Burnett et al., 2018)

Finally, Liu et al. (2018), present a strategic foresight report aimed at advancing multiscale modeling and simulation to enhance supply chain efficiency and innovation. As a foresight and visioning report, it remains a living document, periodically updated to ensure continued relevance. Developed in collaboration with key industry stakeholders and supported by NASA, the roadmap defines a vision for the future of materials and structure modeling by 2040. To maintain its relevance, each gap and recommended action is tied to one or more of the following end-state characteristics: accessible, adaptive, interoperable, robust, traceable, and user-friendly. The study also highlights several materials technologies crucial for advancing multiscale modeling and simulation (Liu et al., 2018).

When the studies conducted in this field are examined, it becomes evident that foresight research related to materials technologies has made substantial contributions to identifying long-term trends, disruptive innovations, and emerging priorities within the defense and aerospace sectors. These studies, particularly those led by NATO, the European Union, and national defense agencies, provide structured roadmaps and scenario-based analyses that inform policy and investment strategies at a strategic level. However, while they offer valuable insights into the future of materials science, they largely remain high-level in scope and do not provide detailed, implementation-oriented frameworks, especially regarding specific material technologies such as honeycomb structures.

Despite the strategic importance of honeycomb materials in advanced aerospace systems, no foresight study to date has directly focused on their future development pathways. This reveals a clear gap in the literature, which limits the ability of defense and aerospace stakeholders to systematically evaluate, prioritize, and integrate honeycomb technologies into long-term planning efforts.

In response, this thesis introduces a mixed-methods foresight framework that incorporates both qualitative data from expert interviews and focus group discussions, along with quantitative tools such as Multicriteria Decision-Making methods embedded within the Futures Wheel, to systematically evaluate and prioritize potential material transformations in aerospace systems. This methodology enables not only the

identification of future honeycomb-related advancements but also the development of actionable strategies for their adoption. By positioning honeycomb materials as a case study, this research bridges the gap between foresight outputs and material-specific implementation, offering a novel contribution that is both methodological and practical in scope.

In summary, this chapter has reviewed the existing literature on foresight methodologies and emerging trends in defense-oriented material technologies. While prior studies have contributed significantly to the field, they often lack the material specificity required to translate foresight into targeted action. This thesis addresses that shortcoming by applying a structured foresight approach to honeycomb materials, demonstrating how foresight can be operationalized to support long-term planning and policy development in aerospace materials, particularly within the context of Türkiye.

CHAPTER 3

THEORETICAL BACKGROUND AND METHODOLOGY

This chapter outlines the mixed-methods approach adopted in this thesis, integrating both quantitative and qualitative research techniques. It first introduces the foresight methods utilized in this research, establishing a conceptual basis. The chapter then details the quantitative techniques employed in the research, including patent analysis and the information related to the multi-criteria decision-making (MCDM) methods. This is followed by a description of the qualitative techniques used, focusing on the use of focus groups and the Reflexive Thematic Analysis (RTA) applied in the backcasting phase. Lastly, the chapter presents the overall research design in a comprehensive manner, explaining each step of the research process in detail, including the focus groups, implementation of AHP, scoring mechanism, and the evaluation criteria.

3.1. Foresight Methods

In this thesis, the Futures Wheel method is selected as an exploratory foresight tool to investigate possible future developments related to honeycomb materials. In addition, Backcasting is employed as a normative foresight approach to identify the necessary steps required to achieve the prioritized future scenario. In this section, both tools are explained in further detail. It is worth highlighting that these foresight methods are not only theoretical frameworks but also actively employed in real-world strategic planning and policy-making. Both the Futures Wheel and Backcasting have been integrated into the official foresight toolkits of several national governments and international organizations. For instance, the governments of the United Kingdom and Australia use these methods to develop scenarios,

anticipate systemic risks, and guide strategic policy decisions (Government Office for Science (UK), 2024; Will Hartigan & Arthur Horobin, 2024).

In order to ensure clarity and consistency throughout the thesis, this study adopts a structured time-horizon framework consisting of three categories: short-term (0–5 years), medium-term (5–10 years), and long-term (10+ years). Time horizons in futures research are known to vary significantly across studies, and there is no universally accepted standard for what constitutes short-, medium-, or long-term. As Nordlund (2012) emphasizes, futures literature often lacks consistent definitions, and scholars such as Bertrand de Jouvenel and Slaughter (1996) have used a range of overlapping terms without strict boundaries. In some of the studies reviewed for this thesis, time-horizon definitions were intentionally left open in order to allow participants greater flexibility in imagining the future, avoiding the imposition of fixed constraints on their foresight thinking (Another Way Consulting, 2015; Bengston et al., 2020). Despite this variability, defining time scales in accordance with the specific sector and national context enhances methodological rigor. In the context of this thesis, which focuses on defense and aerospace technologies in Turkey, short-term is defined as 0 to 5 years, medium-term as 5 to 10 years, and long-term as beyond 10 years. In the context of this thesis, which focuses on defense and aerospace technologies in Turkey, the selected intervals reflect typical product development cycles and strategic planning practices, where projections beyond 20 years often lose practical relevance. Therefore, the time-horizon definitions adopted here are not only methodologically grounded but also tailored to the operational realities of defense and aerospace industry.

3.1.1. Futures Wheel

One of the key exploratory methods used in foresight is the Futures Wheel, developed by Jerome C. Glenn in 1971, a structured brainstorming tool used to explore and map out the potential direct and indirect consequences of a particular change or event. It involves creating a visual representation, often in the form of a wheel, where the central hub represents the initial change or event, and the first-order consequences extend outward from it, branching further to show second-order and subsequent impacts (Glenn, 2009).

As noted by Slaughter (1996), the Futures Wheel has been widely utilized in futures studies as an effective tool for scenario construction. Building on this, Çepni, (2019) defines a scenario not only as a depiction of a possible future state, but also as the path leading to that future. In this context, while the original structure of the Futures Wheel does not explicitly define the branching sequence of impacts as a "path," its methodological logic inherently organizes consequences in a temporally ordered and causally linked manner. The progression from first-order to second- and third-order effects illustrates a structured chain of developments, which can be interpreted as a route from the initiating event to multiple future outcomes. Rather than presenting a static map of isolated possibilities, the Futures Wheel enables a dynamic visualization of how change might unfold over time. Thus, it provides a conceptual and visual foundation for constructing future paths, as it captures the cascading nature of impacts. Figure 3 presents a visual representation of the Futures Wheel, adapted from Glenn (2009), enhanced and color-coded based on my interpretation. In this figure, the branching structure and associated impacts or consequences are color-coded to distinguish between first-, second-, and third-order effects. Moreover, a sample "path" is highlighted to illustrate how a single line of causally connected impacts can represent a scenario path, as discussed above.

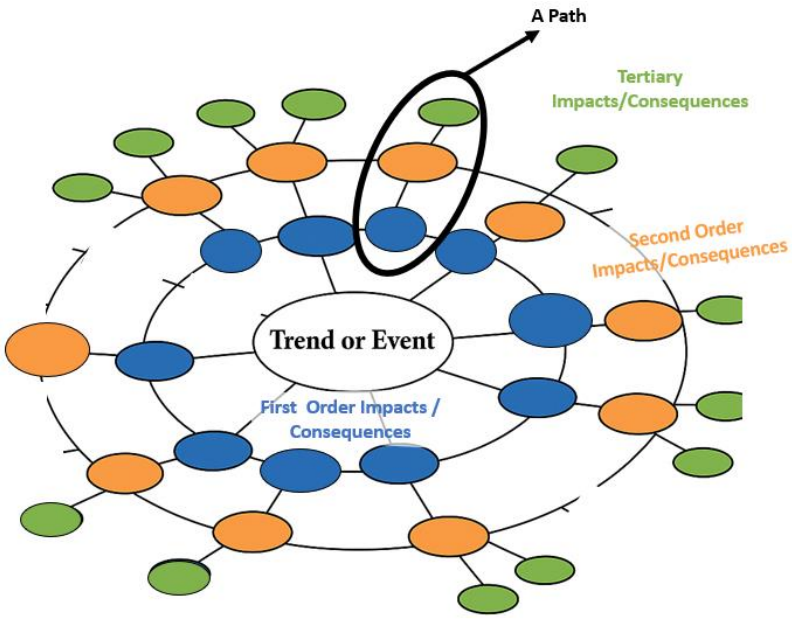


Figure 3. Futures Wheel

Adapted from: Glenn, 2009

Bengston (2016) mentions that The Futures Wheel assists policymakers in predicting unintended effects of social-ecological changes, allowing for proactive decision-making. By showing multiple layers of direct and indirect impacts, it enables the development of strategic responses to complex challenges. The method has been adopted by various government agencies and international institutions as part of their strategic foresight practices. For instance, the UK's Health and Safety Executive (HSE) Foresight Centre used the Futures Wheel during its 2016–2017 planning process to navigate uncertainties related to the national energy mix employing it to assess cascading impacts and develop policy options (UK Health and Safety Executive, 2023). International bodies such as the United Nations Global Pulse (UNGP) include the Futures Wheel in their foresight toolkits, providing guidance on its use for scenario exploration and strategic reflection (UN Global Pulse, n.d.). Notably, in the defense and security domain NATO incorporated the Futures Wheel in its 2017 *Framework for Future Alliance Operations (FFAO)* workshop to explore instability scenarios such as pandemics, infrastructure attacks, and conventional warfare. The method allowed military and non-military experts to collaboratively analyze the cascading effects of such events and validate strategic concepts relevant to future operations (NATO, 2017).

While the Futures Wheel has proven to be a valuable tool for informing policy and strategy, its methodological versatility and flexibility have also enabled the development of new foresight methods that build upon its foundational structure. By providing a structured yet adaptable framework for exploring the direct and indirect consequences of changes, the method can be tailored to address diverse challenges and questions. Whether used in innovation processes, research and development planning, or software development, the Futures Wheel serves as a dynamic tool for visualizing and assessing future possibilities. Its capacity to map out not only immediate impacts but also secondary and tertiary effects allow it to integrate seamlessly with other methodologies, such as goal modeling or foresight approaches. This adaptability has led to the evolution of various methods derived from the Futures Wheel, each designed to meet the specific needs of different fields.

The Futures Ripples method, for example, adapts the Futures Wheel to enhance the pace and anticipatory capacity of innovation teams within their invention processes

(Epp et al., 2022). At its core, this method uses the Futures Wheel to help envision potential future scenarios and guide the development of products or designs. The process is metaphorically described as throwing a pebble into water. It begins by identifying signals of change, which can be seen as scanning the shore, followed by selecting a "what if" scenario, symbolized by the pebble. Then, the ripple effect of this action spreads outward, representing how even small actions can lead to broad consequences. This metaphor illustrates how small changes made today can lead to significant impacts in the future, which is why the method is referred to as "Futures Ripples". The method employs a similar principle to the Futures Wheel, where the "pebble" dropped into the metaphorical sea creates "ripples" of consequences that spread outward, with each successive ring representing further-order effects. To develop and refine the Futures Ripples method, they held a total of four workshops, utilizing online platforms. Epp et al. (2022) introduced this methodology and applied it to explore various potential futures for wearables and smart materials.

The Implications Wheel takes this approach a step further by providing a more in-depth exploration of the consequences that arise from a central issue. Developed by Joel Barker, the Implications Wheel is a meticulously structured brainstorming tool that enables a thorough examination of the potential ramifications of changes across different contexts. Participants can assign numerical ratings to assess likelihood (ranging from 1 to 9) and desirability (ranging from -5 to +5). The software then calculates these values to provide a comprehensive analysis (Another Way Consulting, 2015). While the software is used in professional foresight settings, the available public sources, such as promotional materials or online demonstrations, provide limited technical detail on how the numerical assessments are operationalized or integrated into the broader analytical process. Instead, the emphasis is primarily placed on offering a visual representation of the method and its resulting outcomes. While both Futures Wheel and Implications wheel tools rely on structured brainstorming to uncover various layers of impact, the Implications Wheel places a stronger focus on analyzing the nuances and specificities of the issue at hand (Farrington et al., 2013).

The Industrial Research Institute (IRI), an organization focused on advancing innovation and R&D management, launched the IRI2038 project in 2015 as a long-range foresight initiative aimed at exploring the future of research and development

through the year 2038. As part of this project, it used the Implications Wheel in 2013 to help generate, evaluate, and visualize potential scenarios and their cascading effects on innovation and technology management (Industrial Research Institute, Inc., 2014).

Finally, Pimentel et al. (2011) integrate the Futures Wheel method with the i* goal model in a two-step approach to better foresee and address future changes during the requirements definition phase of software development. The i* goal model is a widely adopted goal-oriented requirements engineering framework that structures system requirements into goals, soft goals, tasks, and resources, and visualizes intentional relationships among system actors. In the first step, the Futures Wheel is employed to identify and visually map the potential consequences of an anticipated event or trend, expanding from direct impacts to secondary and tertiary effects. Each consequence is analyzed to determine its direct impact on the system. In the second step, these identified impacts are translated into concrete adjustments within the i* goal model by adding, modifying, or removing relevant elements such as goals, tasks, soft goals, or resources. This ensures that the system's evolving requirements are aligned with both present conditions and plausible future scenarios.

Given the flexibility and layered analytical capacity of the Futures Wheel method, I considered it particularly appropriate for addressing the first research question of this thesis: "What is the prioritized[1] future of honeycomb materials technologies in the defense and aerospace industries?" I found that the method's structured yet exploratory framework allowed me to systematically identify both the direct and indirect consequences of specific technological developments, which was essential for capturing the cascading effects of advancements in honeycomb materials. The Futures Wheel enabled me to construct interconnected scenario paths and better understand how these technological shifts might unfold over time across multiple dimensions. Since my aim was not only envision possible futures but to evaluate and prioritize among them, the method offered a robust conceptual and visual foundation (Another Way Consulting, 2015; Epp et al., 2022; Farrington et al., 2013; Industrial Research Institute, Inc., 2014; Pimentel et al., 2011). I strengthened this foundation by

[1] This term is explained further in this paragraph.

integrating the Futures Wheel with the Analytic Hierarchy Process (AHP), which allowed me to convert qualitative foresight outputs into a ranked set of future scenarios. While all alternative futures generated through the foresight process are inherently valuable for understanding the breadth of possibilities, establishing a priority among them is essential for strategic planning and effective decision-making (Vecchiato et al., 2020). This combination allowed me for a structured prioritization process to deliver actionable insights. Therefore, I found the Futures Wheel to be well-aligned with the exploratory goals of the study and particularly useful for deriving a strategically prioritized future that could effectively inform the subsequent backcasting phase and the development of policy recommendations.

3.1.2. Backcasting

Backcasting is a normative scenario method aimed at aiding policymakers in navigating the ambiguities linked to long-term future projections (Wilson et al., 2006). It focuses on defining a desired future state and determining the steps and actions required over time to achieve that vision (Bengston et al., 2020). The term was formally introduced by John B. Robinson in 1982, who employed it as a means to shape energy policy through the structured exploration of pathways leading to desirable outcomes (Robinson, 1982). Since then, it has become a foundational approach within strategic planning and futures studies, particularly in addressing sustainability and technology-driven transitions. Backcasting is particularly well-suited for addressing long-term, multifaceted challenges that span various societal dimensions and require technological innovation and systemic change (Dreborg, 1996). By starting from a future vision rather than current conditions, it provides a sense of cognitive liberation, enabling stakeholders to think beyond the constraints of existing customers, products, or capabilities (Thorén & Vendel, 2019).

Backcasting is a future-oriented planning method that starts with a vision of a desirable future and then works backwards to identify the necessary steps to reach that future. Unlike forecasting, which begins with the present and extrapolates forward based on trends, backcasting asks: “If we want to achieve this future, what needs to happen between now and then?” (Quist, 2003). This method is especially useful when current

trends are unlikely to lead to sustainable or strategic outcomes on their own, and when proactive planning is required to drive transformational change(Wilson et al., 2006).

While “backcasting” remains the dominant term in futures research, the conceptual approach has been adapted and renamed in various contexts to suit different disciplinary or practical needs. For instance, Rohrbeck (2011) uses the term “scenario-based retropolation” to describe the process of using future scenarios to inform present-day decisions. Similarly, the term “premortem” often seen in project planning contexts, emphasizes the practice of looking back from a desired future outcome to identify the key success factors and motivational elements that can guide present actions (Klein, 2008). This terminological variety illustrates the adaptability of the method across different domains, from corporate strategy to public policy.

As the method gained wider adoption across disciplines and planning contexts, efforts were made to operationalize backcasting through more structured tools that could translate normative visions into practical strategies. One such tool is the Backcasting Wheel, introduced as a way to systematically organize actions, actors, and resources around a central future goal within futures studies (Bengston et al., 2020). Inspired by the logic of the Futures Wheel, this method shifts the focus from extrapolating future impacts of current trends to identifying the essential components required to realize a normative vision. The Backcasting Wheel incorporates several key dimensions, including critical success factors, signposts, opportunities and obstacles, and concrete management actions. These elements are organized around a central future goal, allowing stakeholders to map not only what must be done but also how progress can be monitored and what challenges or enabling conditions may arise. A case study of the U.S. Forest Service’s organizational planning was used to demonstrate the practical application of the method, showing how it can facilitate participatory decision-making and guide the development of actionable, long-term strategies in the context of institutional and environmental policy planning (Bengston et al., 2020)

Beyond conceptual development, numerous case studies have demonstrated the practical value of backcasting across diverse domains, particularly in sustainability and urban planning. For example, Kok et al. (2011) employed backcasting to transform stakeholder-derived visions of sustainable water management into detailed and

actionable policy roadmaps. The method not only enabled the identification of robust strategies applicable across multiple futures but also enhanced stakeholder engagement and policy relevance. Similarly, Olson et al. (2021) used a participatory backcasting approach to design a roadmap for reducing consumption-based emissions in Hammarby Sjöstad, a sustainable urban district in Stockholm, by 2030. In addition to academic and applied settings, the method has gained traction among major policy institutions. For example, the European Commission, through its Joint Research Centre's Institute for Environment and Sustainability (2008), has endorsed backcasting as a valid approach for forward-looking policy development. In their work on sustainable mobility, the method was applied to construct long-term strategies that incorporate stakeholder input, define specific actions, and develop coherent pathways toward ambitious sustainability goals in the transport sector.

In selecting the appropriate foresight method to address my second research question: "What policies are needed to enable the realization of the prioritized future?", I chose Backcasting due to its unique suitability for translating normative future visions into actionable strategies. Given that the prioritized future of honeycomb materials will be previously identified through the Futures Wheel and AHP prioritization, Backcasting will provide a structured way to explore how that future can be operationalized through coordinated actions, I find this method particularly valuable for engaging stakeholders in long-term thinking, beginning with the establishment of a strong shared future path and then working backward to align short-term policies with broader strategic goals.

3.2. Quantitative Methods

3.2.1. Patent Analysis

Patent analysis involves examining patent documents related to specific area by applying data analysis techniques, including statistical and machine learning methods (Park & Jun, 2022). Patent documents, which are legal records of inventions, contain detailed descriptions of novel ideas, processes, and technologies. These documents serve as a rich source of data for various sectors to assess technological advancements and identify future developments. Patent analysis provides valuable insights for evaluating technological advancements, monitoring emerging trends, managing the

R&D process, and developing technological strategies (Chang et al., 2010, p. 201). It provides valuable insights into the direction of technological change and helps anticipate future developments. Patent analytics can identify business markets and trends, assisting companies in anticipating technological shifts and market changes. This process includes mapping, categorization, and the use of taxonomies to interpret market directions (Questel & Chevalier, 2020). By analyzing patent topical information, potential technology pathways and opportunities can be uncovered (Ma & Porter, 2015) which makes patent analysis an ideal method for investigating material technologies that could drive critical transformation.

Patent analysis can be considered a valid foresight tool, as it is employed in strategic long-term planning. Foresight methods aim to predict future technological landscapes, and patent analysis is particularly effective in this regard, as patents typically have a lifespan of 20 years. This long-term data allows for the identification of trends and innovations that may shape future industries (Hsieh, 2013). As Popper (2008) classifies patent analysis as a foresight method, it serves as an effective tool for predicting long-term technological change and for developing strategies based on these insights. In support of this view, Daim et al. (2006) demonstrate how patent analysis can serve as a proxy for technological innovation and development, revealing underlying patterns, competitive positioning, and likely future trajectories of technological evolution.

Patent analysis is highlighted as a valuable strategic foresight tool by Salvador et al., (2015), who emphasize its role in informing decision-makers about patent activity, technological advancements, and key industry players. Their research specifically applies patent analysis to the field of additive manufacturing, demonstrating how patent data helps identify technological trends and supports strategic decision. Similarly, another study focuses on the utilization of patent information to develop bioethanol technology from sorghum plants, showcasing how foresight tools predict advancements in this sector (Hendrix & Nasution, 2023).

In the context of defense technologies, patent analysis has also found practical applications in tracking technological developments. For instance, Altuntaş & Dereli

(2016) employ this method within the domain of Ammunition and Blasting Technologies. Their research aims to guide investors, policymakers, and other stakeholders in navigating complex defense innovation landscapes. By uncovering technological developments through patent trends, their study highlights the potential of patent analysis to support long-term capability planning in critical sectors of national security.

3.2.2. Multi-Criteria Decision Making (MCDM)

Multi-Criteria Decision Making (MCDM) also referred to as Multi-Criteria Decision Analysis (MCDA), encompasses a comprehensive set of methodologies aimed at facilitating complex decision-making processes that involve multiple, and often conflicting, evaluation criteria. The formal academic development of Multi-Criteria Decision Making (MCDM) is relatively recent; however, the underlying notion of considering multiple factors in decision-making has much earlier roots. Köksalan et al. (2011) trace one of the earliest known decision-making procedures involving multiple considerations to Benjamin Franklin (1706–1790), who described a paper-based system for weighting arguments for and against a decision. Though rudimentary and lacking formal weighting, Franklin's method demonstrated early awareness of balancing conflicting arguments—an idea at the heart of modern MCDM.

Building on these early intuitions and mathematical formalizations, significant theoretical advancements were made in the 1970s and 1980s by scholars such as Zionts and Wallenius. While the contemporary literature commonly refers to this field as Multi-Criteria Decision Making (MCDM), Zionts & Wallenius (1976) originally framed the challenge as the "multiple criteria problem," emphasizing the inherent difficulty of making trade-offs among conflicting objectives. They define it as a class of problems in which decision-makers must evaluate alternatives across several incommensurable criteria, often under uncertainty, and highlight the value of interactive and iterative preference articulation. In addition to these theoretical contributions, Zionts also played a notable role in shaping the terminology of the field by the abbreviation "MCDM" through a 1979 paper that clarified its meaning and emphasized its practical relevance in managerial decision-making (Zionts, 1979).

These methods enable decision-makers to systematically analyze and prioritize a set of alternatives by making the trade-offs between criteria explicit, thereby supporting rational decision outcomes (Velasquez & Hester, 2013). MCDM frameworks provide structured mechanisms for comparing alternatives and clarifying priorities in complex decision environments (Belton & Stewart, 2002). Importantly, MCDM draws upon a range of interdisciplinary fields, including mathematics, decision science, management, economics, psychology, and social science, making it a highly versatile and multidisciplinary approach to decision support (Ishizaka & Nemery, 2013).

While Multi-Criteria Decision-Making (MCDM) methods vary in mathematical formulation and procedural detail, they generally follow a structured, step-by-step process that guides the systematic evaluation and selection of the most appropriate alternative(s) among a set of options. This common structure allows decision-makers to decompose complex problems into manageable parts and to make judgments in a rational and transparent manner (Belton & Stewart, 2002; Epp et al., 2022; A. Salo et al., 2003; Zhu et al., 2021). The common steps identified across these three studies are outlined below.

It begins with problem structuring and the definition of key elements, which involves clearly identifying the decision goal, the criteria used to assess alternatives, and the alternatives themselves. The goal represents the desired outcome, while criteria are the dimensions either quantitative (such as cost or efficiency) or qualitative (such as environmental impact or stakeholder acceptance) used to evaluate the alternatives. Alternatives refer to the potential options or pathways from which a decision-maker must choose. Following this, the elements are arranged in a hierarchical decision model, with the goal at the top, followed by criteria and sub-criteria, and the alternatives at the bottom. This structure simplifies complexity and enhances transparency. At this stage, appropriate measurement scales are also defined to ensure consistency in how alternatives are evaluated against each criterion. The next step is weight assignment where each criterion is assigned a relative importance weight. A variety of techniques can be employed to derive these weights, including direct rating, entropy-based methods, and pairwise comparison techniques (Zhu et al., 2021). Once

weights are determined, the alternative evaluation phase involves assessing each option against the criteria, using empirical data, expert judgment, or both. Finally, in the aggregation and synthesis step, the individual performance scores and criterion weights are mathematically combined to compute an overall value for each alternative. This results in a ranked ordering that supports transparent and evidence-based decision-making (Figueira et al., 2005).

Multi-Criteria Decision-Making (MCDM) methods have also found significant application within foresight practices, particularly in addressing complex, uncertain, and multi-dimensional strategic problems. Popper (2008) identifies MCDM as a core component of semi-quantitative foresight methodologies, referring to it as multi-criteria analysis used to structure and assess expert-based judgments. Similarly, Salo et al. (2003) emphasize the value of MCDM in priority-setting within technology foresight, where it helps manage the inherent complexity of research and technology development (RTD) strategies. They highlight methods such as SMART, AHP, PRIME, and DEA as particularly suitable, noting their ability to incorporate diverse stakeholder perspectives, multiple evaluation criteria, and uncertainty. Further illustrating this integration, Mohaghar et al. (2013) apply a combination of the Fuzzy Prioritization Method (FPM) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to support strategic decision-making under conditions of incomplete information. In this way, MCDM contributes to foresight by providing a structured, transparent, and evidence-based framework for evaluating future-oriented decisions.

While a wide range of MCDM approaches exist, the methods highlighted in foresight literature such as SMART, AHP, PRIME, DEA, FPM, and TOPSIS stand out due to their ability to address uncertainty, accommodate diverse criteria, and support transparent strategic evaluation**.** Table 4 provides a comparative overview of these selected methods, summarizing their key features, strengths, and limitations, as well as citing foundational references for each. This overview aims to offer practical insight into the suitability and application of MCDM techniques within foresight-oriented decision-making processes.

Table 4. Overview of Selected MCDM Methods in Foresight Applications

Method	Brief Description	Weighting Mechanism	Strengths	Limitations	Key Reference
SMART (Simple Multi-Attribute Rating Technique)	A linear method decision-makers assign weights and scores directly.	Yes (direct weighting)	Easy to use, intuitive, Simple and transparent	Sensitive to subjective judgments may oversimplify complex problems.	(Edwards, W., 1971; A. Salo et al., 2003)
AHP (Analytic Hierarchy Process)	Uses pairwise comparisons and hierarchical structuring to derive priority scales.	Yes (pairwise comparisons)	Handles both qualitative and quantitative data, strong consistency checks, Easy to understand	Can be time-consuming, consistency issues in large hierarchies.	(Saaty, 1980; Saaty & Vargas, 2012)
PRIME (Preference Ratios in Multiattribute Evaluation)	Aims to elicit incomplete and imprecise preference information for decision support.	Yes (indirect, interval-based)	Accommodates incomplete and imprecise preferences; flexible.	May require sophisticated interpretation; less commonly applied.	(A. A. Salo & Hamalainen, 1997)
DEA (Data Envelopment Analysis)	Non-parametric method to assess the relative efficiency of decision-making units.	No explicit weights; derived from data.	Objective, data-driven, useful for benchmarking.	Not suitable when data quality is poor; assumes all inputs/outputs are known.	(Charnes et al., 1978)
FPM (Fuzzy Prioritization Method)	Incorporates fuzzy logic to handle uncertainty and vagueness in prioritization.	Yes (fuzzy weights)	Manages uncertainty effectively; useful in strategic foresight.	Interpretation of fuzzy numbers can be complex.	(Mohaghar et al., 2013)
TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)	Ranks alternatives based on their geometric distance to ideal/baseline solutions.	Yes (weights required)	Simple to compute; clear ranking of alternatives.	Sensitive to normalization and weighting.	(Figueira et al., 2005)

Table 4. (continued)

Goal Programming	An extension of linear programming that allows decision-makers to set target values for multiple goals and find solutions that minimize how far the results are from these targets.	Yes (weights or priority ranking)	Handles multiple goals flexibly; useful for real-world trade-offs.	Requires clear goal definitions; assumes linear relationships.	(Charnes et al., 1955; Charnes & Cooper, 1957)

Source : Author

In this thesis, MCDM methods are employed not for evaluating or ranking a set of alternatives, but rather for the purpose of determining the relative importance of a predefined set of criteria. The primary objective of using MCDM is to assign weights to three main criteria relevant to this technological and policy context. Thus, among the components of MCDM approaches, only the weighting mechanism is required, while the alternative evaluation phase is not part of this study. Given this focus, and considering the range of available MCDM techniques, AHP emerges as the most appropriate choice because of the following reasons:

- It structures expert judgment into a systematic, transparent, and consistent weighting scheme, enabling clear prioritization of decision criteria.
- It employs pairwise comparisons, allowing experts to express their preferences in a more intuitive and comparative manner rather than assigning direct numerical weights.
- It includes a Consistency Ratio (CR), which helps assess the logical coherence of expert judgments and ensures methodological validity.
- It balances mathematical rigor with ease of use, making it suitable for interdisciplinary research involving both technical experts and policy stakeholders.
- It does not require large datasets or complex mathematical modeling, making it particularly useful in foresight and policy contexts where qualitative input dominates.

- It also has the step for directly on criteria weighting, which aligns precisely with the methodological needs of this thesis, as no alternative evaluation is required.

These features make AHP the most fitting and robust method for the objectives and scope of this thesis.

3.2.2.1. AHP

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty (1980), is a widely adopted multi-criteria decision-making (MCDM) method that provides a systematic and rigorous framework for organizing and analyzing complex decisions (Saaty, 1980). It is particularly suitable for problems that involve both quantitative and qualitative factors and require structured expert input (Saaty & Vargas, 2012).

AHP functions on the principle of "divide and conquer," whereby complex problems are decomposed into smaller, more manageable sub-problems (Ishizaka & Nemery, 2013). AHP has proven to be a reliable and widely applicable decision-making method, as evidenced by its use in diverse fields such as student admissions, military personnel promotions, hiring decisions, and various military and political contexts (Saaty, 2008) .

The AHP method follows a structured and hierarchical procedure for determining priorities among elements. Although this thesis focuses solely on the weighting of criteria, it is important to present the full framework of AHP to demonstrate its methodological rigor. Below, the process is outlined in sequential steps (Saaty, 1980, 2008; Saaty & Vargas, 2012):

1. Problem Definition and Hierarchy Construction
   The decision problem is first structured as a hierarchy. At the top is the overall goal of the decision. The second level consists of the evaluation criteria. If the aim is to rank alternatives, these would be placed at the third level. Let n denote the number of criteria.

2. Pairwise Comparison Matrix Formation:
Experts are asked to compare the criteria in pairs, using Saaty's fundamental 1–9 scale, as shown in Table 5 below, to express the relative importance of one criterion over another. This generates a pairwise comparison matrix *A*, where element a_{ij} reflects how much more important criterion i is compared to criterion j. The matrix is reciprocal, meaning $a_{ij} = 1/a_{ji}$. For example, if an expert believes that Criterion A is strongly more important than Criterion B, then $a_{AB}=5$ and correspondingly $a_{BA}=1/5$. Additionally, each diagonal element of the pairwise comparison matrix is always equal to 1($a_{ii}=1$), because any criterion is considered equally important when compared with itself.

Table 5. The Fundamental Scale for AHP Pairwise Comparisons

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Source: Saaty & Vargas (2012)

3. Normalization of the Pairwise Matrix:
Each element in the matrix is divided by the sum of its column, producing a normalized matrix. This step ensures that each column sums to 1, allowing for

meaningful comparison across criteria. The normalization of the pairwise comparison matrix is performed by dividing each element by the sum of its respective column, as shown in the following formula:

$$a_{ij}^{normalized} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (1)$$

Where *n* is the number of criteria.

4. Priority Vector Calculation (Weight Assignment):
   The priority vector (also called the eigenvector or weight vector) is computed by taking the average of each row in the normalized matrix. This vector represents the relative weight of each criterion with respect to the decision goal.

$$w_i = \frac{1}{n}\sum_{j=1}^{n} a_{ij}^{normalized} \quad (2)$$

5. Consistency Check
   AHP includes a built-in mechanism to verify the logical consistency of the pairwise comparisons. The Consistency Index (CI) is calculated as:

$$\lambda\text{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(\text{A}.w)_i}{w_i} \quad (3)$$

$$CI = \frac{\lambda\text{max} - n}{\text{n} - 1} \quad (4)$$

where λmax is the maximum eigenvalue of the comparison matrix and n is the number of criteria. The Consistency Ratio (CR) is then calculated as:

$$CR = \frac{\text{CI}}{RI} \quad (5)$$

where RI is the Random Consistency Index which varies depending on n as presented in Table 6 below. A CR value of less than 0.10 is generally considered acceptable. If the CR is too high, the comparisons should be reviewed and revised.

Table 6. Average Random Consistency Index (RI) Based on Matrix Order(Criteria number) (n)

n	1	2	3	4	5	6
Random Consistency Index (RI)	0,00	0,00	0,52	0,89	1,11	1,25

Source: Saaty & Vargas (2012)

6. Evaluation of Alternatives:
   If the study involved alternatives, each alternative would be evaluated against each criterion, using the same pairwise comparison process. For each criterion, a local priority vector for the alternatives would be computed.
7. Aggregation of Local Priorities:
   The final step in a full AHP application is to aggregate the local priorities of alternatives across all criteria using a weighted sum. The global score for each alternative is calculated as the sum of the product of the criterion weight and the alternative's score for that criterion. Alternatives would then be ranked based on their global scores.

In this study, since no alternatives are assessed, the procedure ends at the point of criteria weight assignment. Nevertheless, the consistency check is conducted at this stage as well, given its significance in ensuring the reliability of expert judgments. The resulting weight vector provides a prioritized structure that reflects expert judgment and serves as a critical input for subsequent foresight analysis and policy development. In group decision-making using the AHP, it is important to determine how individual expert evaluations can be combined into a shared group judgment and how these evaluations contribute to a final collective decision. According to Saaty (2008), the

most appropriate method for combining individual expert assessments is the geometric mean, as opposed to the commonly used arithmetic mean, as it ensures consistency in how relative importance is represented across experts. When each expert provides their own assessment independently, their resulting weight vectors, which reflect the relative importance of criteria, can be combined using the geometric mean to create a representative group perspective.

In this study, each expert's judgment was treated with equal weighting in the aggregation process, meaning that no differentiation was made based on background or institutional affiliation. Therefore, individual weight vectors were first calculated from each expert's input, and then the geometric mean of these vectors was taken to produce a single group weight vector. The geometric mean for each criterion w_i was calculated as follows:

$$w_i = \sqrt[m]{\prod_{k=1}^{m} w_i^{(k)}} \tag{6}$$

where $w_i^{(k)}$ denotes the weight assigned to criterion i by expert k, and m is the number of experts. Finally, the resulting values were normalized to ensure that the total importance across all criteria adds up to one, using the following normalization formula as n is the number of criteria:

$$w_i^{normalized} = \frac{w_i}{\sum_{j=1}^{n} w_j} \tag{7}$$

Finally, the results were normalized to ensure that the total importance across all criteria adds up to one. [2]

3.3. Qualitative Methods

[2] For a summary of the mathematical notations and symbols used throughout the AHP process, please refer to Appendix A of this thesis.

In this study, the qualitative component of the mixed-methods design is centered on focus group sessions, which were employed to gain in-depth insights into participants' opinions and policy recommendations regarding the future of honeycomb materials in defense and aerospace sectors. Historically, the academic foundations of focus groups originate from Merton et al., (1956) whose work institutionalized the "focused interview" as a systematic tool for studying group-based opinion formation. Patton, (2010) highlights how focus group interviews enable researchers to access social dynamics and patterns of interaction, yielding rich qualitative data when guided by a skilled moderator. The value of interaction in this setting lies in the emergence of shared or contested meanings, shaped by participants responding to one another rather than simply to the interviewer.

As Creswell (2022) suggests, qualitative research is particularly appropriate when the research questions begin with "what" or "how," when the aim is to understand individuals within their real-world contexts, and when the focus is on gaining a holistic understanding. Given the exploratory nature of this study, the qualitative approach was well-suited to capture the complexity and depth of stakeholder perspectives.

I selected focus groups because they offered a structured yet flexible format to explore emerging ideas in a collaborative setting, which was essential for uncovering the anticipatory thinking and multi-stakeholder perspectives that this study aimed to investigate. The selection of focus groups as the primary qualitative tool is supported by their proven ability to generate collective insights, foster dialogue, and surface diverse perspectives that may not emerge through individual interviews or surveys (Morgan, 1997).

Focus groups are widely recognized within the field of foresight and science and technology studies as participatory tools that not only gather information but also raise awareness and stimulate forward-looking thinking among stakeholders as emphasized by Grunwald (2009). They are often employed in foresight processes alongside citizens' conferences, Delphi studies, or scenario workshops to elicit anticipatory knowledge and engage multiple actors in shaping technological developments, a role highlighted by Popper (2008). In this context, the inclusion of diverse stakeholder

groups is particularly important. It enhances the quality of deliberation, strengthens anticipatory capacity, and supports more legitimate and inclusive policy outcomes (Grunwald, 2009; Popper, 2008). Yet, as Bloor et al., (2001) mention participant imbalances are common in expert-based focus groups, and methodological rigor can still be maintained through deliberate facilitation techniques.

I analyzed the qualitative data from the second focus group using Reflexive Thematic Analysis (RTA) (Braun & Clarke, 2019). Thematic analysis is defined as "a method for identifying, analyzing, and reporting patterns (themes) within data" (Braun & Clarke, 2006, p. 79) RTA extends this by emphasizing the interpretative and active role of the researcher in constructing meaning from data, rather than treating themes as objectively emerging from the material. This view aligns with McCracken's(1988) conceptualization of the "self-as-instrument," where the researcher draws on their own cognitive and experiential repertoire to detect meaningful patterns. In line with this perspective, the research process acknowledged the influence of the researcher's positionality, assumptions, and reflexivity, which were managed through techniques such as memoing and critical self-awareness (Finlay, 2002). Moreover, Corbin & Strauss (1996) emphasize that qualitative analysis involves deliberate mental movement between concrete data and abstract concepts, using analytic strategies to help the researcher think systematically and identify deeper relational patterns.

This study's approach aligns with Braun & Clarke's (2019) framework for RTA, which underscores that theme development is a dynamic and iterative process shaped by the researcher's engagement with the data. The analysis followed a six-phase process commonly used in thematic analysis: data familiarization, initial coding, theme identification, theme review, definition and naming of themes, and final reporting (Kiger & Varpio, 2020). However, reflecting the interpretative and reflexive nature of RTA, this process was not linear but cyclical, allowing ongoing refinement through multiple iterations (Braun & Clarke, 2019).

This study was conducted in accordance with ethical standards and received approval from the METU Human Subjects Ethics Committee (HSEC) on May 12, 2025, under

protocol number 0211-ODTÜİAEK-2025. Please refer to for the official ethics approval letter.

3.4. Research Design

In alignment with the research questions, I adopted a mixed-method approach incorporating both quantitative and qualitative techniques in a sequential manner. I chose this approach allows me to quantify qualitative insights, enrich numerical data with contextual understanding, address research questions from multiple perspectives that may be overlooked by single-method approaches, and enhance both the credibility and applicability of the findings (Creswell, 2022). I intentionally structured methodological progression to reflect the dual nature of foresight: exploring possible futures (exploratory) and identifying policy recommendations to achieve a desired outcome (normative). By combining exploratory methods and normative methods I aim to produce actionable intelligence for policy-making (Popper, 2008). In this context, actionable intelligence refers to policy-relevant insights that are grounded in expert judgment, structured foresight outputs, and prioritized future scenarios, offering concrete guidance for decision-makers. This decision was driven by the complexity and future-oriented nature of the research aim which requires both the identification of emerging technological developments and the formulation of policy.

To ensure methodological coherence and alignment with the research questions, I designed each phase of the study to contribute to the overall aim. As illustrated in Figure 4, the research design links each phase to the corresponding research question and methodological approach. The first research question, which explores the prioritized future of honeycomb materials technologies in the defense and aerospace industries, was addressed through a sequence of steps that I designed, including patent analysis to validate the relevance of the case, the application of the Futures Wheel method to generate possible future developments, and the use of the Analytic Hierarchy Process to weight the criteria and systematically prioritize these futures based on predefined criteria and weighted sum.

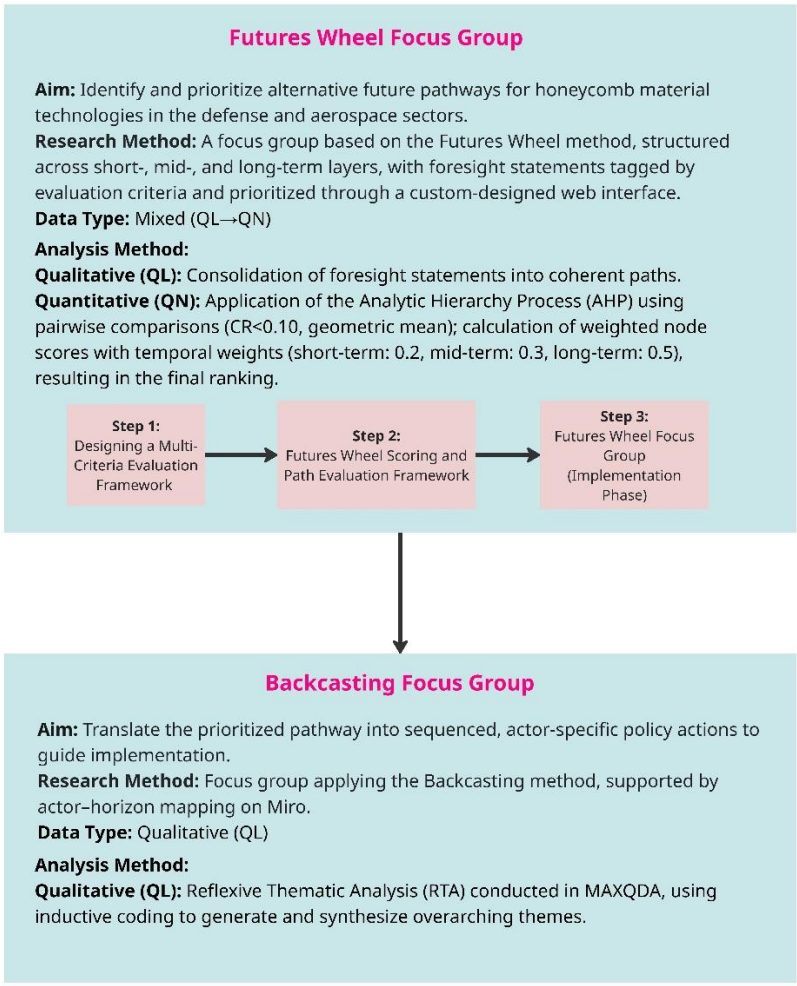


Figure 4. Research Design and Methodological Flow

Source: Author

These steps enabled me to establish a foundation for identifying the most strategic and relevant future path. The second research question, which focuses on the policy suggestions required to realize this prioritized future, was explored through using the Backcasting method. Building on the outcome of the previous phase, this approach allowed me to identify of necessary actions and policy suggestions by working backwards from the desired future state. The integration of these methods helped me create a coherent and structured process from technological foresight to concrete policy recommendations, ensuring that both exploratory and goal-oriented dimensions of the research were addressed.

3.4.1. Patent Analysis for Case Validation

I conducted a patent analysis to test for the strategic importance and future relevance of honeycomb materials technology within the defense and aerospace sectors. While the literature review highlights the significance of this technology, I included this step as an additional empirical check to ensure that the selected case reflects a technology that remains active and influential in current and emerging landscapes. The patent analysis was therefore not conducted as an independent core component of the research, but as a supportive input to validate the case selection before applying foresight methodologies.

For this purpose, I utilized the Espacenet database provided by the European Patent Office, and the PatSeer platform, which enables advanced patent analytics and visualizations. I focused specifically on the B64 classification from the International Patent Classification (IPC) system, which encompasses technologies related to "Aircraft; Aviation; Cosmonautics." This classification offers a comprehensive overview of innovation in aerospace systems, making it highly relevant to the research scope. To capture recent technological developments, I limited the search to granted patents published within the last ten years. Additionally, I examined the intersection between the B64 class and selected materials technology subclasses, to identify patents related to advanced materials applicable to aerospace contexts.

As shown in Figure 5 the IPC subclass B32B3/12 which refers to layered products made up of regularly arranged cells (such as honeycomb structures) stands out with 325 patent families. Although it appears as the second most active subclass in terms of total patents, it is particularly relevant to this study because it reflects a structural, technology-oriented classification rather than a general functional one, like adhesives. In fact, B32B3/12 includes the highest number of patents related to honeycomb forms, with approximately 57% of the entries in this class specifically addressing honeycomb materials technology. Other classes (such as those covering adhesives or generic composites) were excluded because they are too broad and not specific to honeycomb structures, which would have weakened the focus of the analysis. By selecting B32B3/12, the analysis was able to capture the closest technological representation of

honeycomb materials while maintaining alignment with aerospace applications under the B64 category.

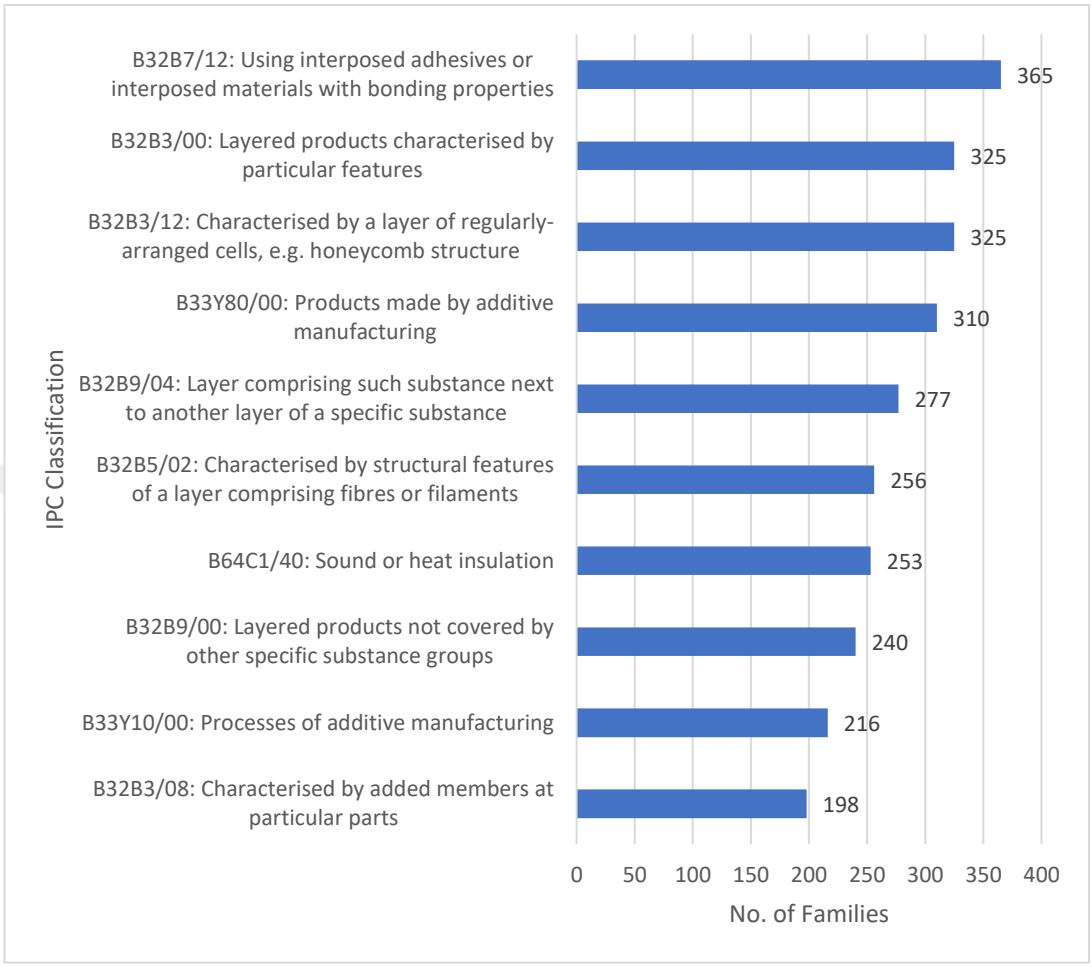


Figure 5. Top IPC Classifications in Aerospace Materials Patents (Last 10 Years)
Source: Espacenet

To contextualize the relevance of honeycomb materials within broader materials technology, I analyzed the long-term evolution of patent families in related IPC classes. A patent family refer to a set of patent applications filed in multiple countries to protect the same invention, making it a useful indicator of both technological relevance and international strategic interest.
This analysis aimed to assess whether honeycomb technologies have retained strategic relevance and momentum over time, beyond being a past technological trend.

As shown in Figure 6 , patenting activity in this domain dates back to the early 1980s, indicating an early technological interest. However, a significant acceleration in filings

begins after 2005, suggesting a renewed wave of developments and likely reflecting increased research investments and demand in aerospace and defense sectors.

The slight decline in patent filings after 2020 is likely due to publication delays rather than an actual drop in technology development activity, as patent applications typically undergo an 18-month confidentiality period. This is consistent with patterns observed in other emerging technologies. Despite this, the overall growth trajectory remains positive, with the total number of patent families surpassing 12,000 by 2023.

These findings confirm that honeycomb materials represent not only historically significant technology but also one that continues to evolve and attract development. This validates their selection for foresight-based policy planning, highlighting its potential to shape future defense and aerospace sectors.

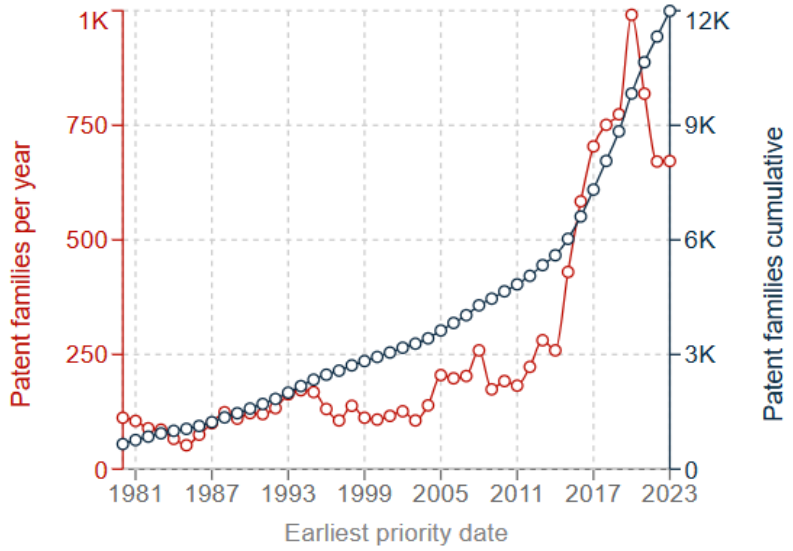


Figure 6. Long-Term Patent Trends in Advanced Structural Materials (1981–2023)

Source: Espacenet

3.4.2. Designing a Multi-Criteria Evaluation Framework

Quantitative prioritization of foresight outputs regarding honeycomb materials in the defense and aerospace sectors requires more than simply identifying possible technological developments (A. Salo et al., 2003). It necessitates a structured evaluation framework that can guide consistent and analytically grounded decision-making. To support this process, I used the Futures Wheel method to generate foresight

statements, each reflecting potential future development. However, to compare these statements in a consistent and structured manner and prioritize them within broader future paths, I established a scoring system.

To enable this, I first developed a multi-criteria evaluation framework. Relying on a single factor would have oversimplified the process and introduced ambiguity in participant interpretation because it is an issue widely noted in foresight and decision-making literature (Hines, 2008; Popper, 2008). Moreover, not all criteria hold the same importance in participants' minds (Salo et al., 2003). Recognizing that criteria may not contribute equally to decision-making, I applied the Analytic Hierarchy Process (AHP) to calculate their relative weights. In line with this, I structured the AHP hierarchy by defining the decision goal as determining the relative importance of the criteria used to evaluate foresight statements related to materials technologies in defense and aerospace contexts, as discussed earlier in this section and following similar practices observed in previous foresight studies that integrate AHP for scenario prioritization (Another Way Consulting, 2015; Epp et al., 2022; A. Salo et al., 2003; Vecchiato et al., 2020) .

Through a review of major foresight and strategic technology assessment reports, particularly those from the European Commission (Farinha et al., 2023), NASA Vision 2040 (Liu et al., 2018) , and the Australian Department of Defence (Burnett et al., 2018), I identified three evaluation criteria that appeared especially relevant for assessing material technologies within the defense and aerospace context. These are: impact on the future, operational application areas, and dual-use potential. These dimensions were emphasized, either explicitly or implicitly, across the reviewed sources, and I selected them based on their conceptual clarity, strategic relevance, and alignment with the objectives of this study.

Impact on the future refers to the extent to which a given materials technology development is likely to transform or strategically influence defense and aerospace systems over time. It captures a spectrum from incremental developments to technologies capable of driving radical transformation, reshaping industrial dynamics,

or serving as foundational enablers of new paradigms. The JRC Science for Policy Report (Farinha et al., 2023) identifies long-term impact as a key criterion in the evaluation of future critical technologies rating process. Similarly, the Australian Department of Defence foresight study (Burnett et al., 2018) prioritizes technologies that are novel, disruptive, and transformative over the long term, supporting this criterion's inclusion.

Operational application areas assess the degree to which materials technology can perform effectively across multiple environmental and operational settings such as land, air, sea, or space. Technology that is highly adaptable and ready for integration into diverse mission environments without significant modification would score higher, whereas context-dependent or specialized solutions would score lower. This criterion draws heavily from the NASA Vision 2040 Report (Liu et al., 2018), which emphasizes cross-domain applicability, scalability, and mission flexibility as core requirements for next-generation aerospace systems.

Dual-use potential measures the extent to which materials technology developed for military use can be transferred to civilian contexts, or vice versa. This dimension is especially relevant in today's increasingly interconnected innovation ecosystems, where technologies with cross-sector applicability can enhance both economic and strategic value. While the JRC report (Farinha et al., 2023) does not always label this attribute explicitly, it highlights the importance of transferability, reduced dependency, and spillover effects. In this context, reduced dependency refers to decreasing reliance on foreign or single-source technologies by strengthening domestic innovation capacity and enabling local adaptation. Moreover, spillover effects occur when innovations developed for military use are later adopted in civilian sectors, thereby contributing to broader technological and economic benefits. Similarly, The NASA report (Liu et al., 2018) states transferability as structural principles, reinforcing the importance of considering technologies that serve both defense and civilian sectors.

Together, these three criteria form a comprehensive and policy-relevant framework for evaluating foresight statements related to materials technologies, offering a balance between strategic vision, operational feasibility, and innovation diffusion potential.

3.4.3. Futures Wheel Scoring and Path Evaluation Framework

In this stage of the study, I developed a scoring framework to systematically evaluate foresight statements generated through the Futures Wheel method. These statements, each representing a potential development in honeycomb materials technologies, were assessed by participants during the focus group. The goal of this framework was to enable the prioritization of future path based on multi-criteria evaluation supported by both expert judgment and analytic weighting.

To calculate weights, I intent to propose a pairwise comparison to each participant in the beginning of the focus group session, following the principles of the Analytic Hierarchy Process (AHP). In this step, I asked participants to compare each criterion against the others in terms of importance. Using the responses collected through this exercise, I planned to calculate the relative weights of the three criteria after futures wheel focus group in analysis phase. These weights served as the basis for a structured scoring system, grounded in expert judgment and aligned with the strategic objectives of the defense and aerospace context.

After establishing the criterion weights, I asked each participant to evaluate every foresight statement generated through the Futures Wheel according to the same three criteria: impact on the future, operational application areas, and dual-use potential. To ensure consistency and clarity in evaluation, I designed a custom 5-point rating scale for each criterion, where every score from 1 to 5 was matched with a clear and context-specific verbal definition. In Table 7 the criteria and the relevant points are shown.

Table 7. Scoring Scale for Criteria

Score	Impact on the Future	Operational Application Areas	Dual-Use Potential

1	Materials technology or its associated development will not create significant change compared to existing technologies.	Materials technology or its associated development is viable only in specific applications and constrained environments, such as low temperatures or tightly controlled pressures.	Materials technology or its associated development is specific to defense aerospace and cannot be used in other sectors.
2	Materials technology or its associated development may offer minor improvements but does not enable large-scale transformation.	Materials technology or its associated development demonstrates limited environmental robustness, functioning under some conditions but failing to adapt to extremes or variability	Materials technology or its associated development is usable in either defense or civil aerospace but not applicable to non-aerospace sectors.
3	Materials technology or its associated development presents a notable innovation in a specific area and can accelerate progress.	Materials technology or its associated development can operate in multiple environments (land, sea, air) with basic functionality but requires modifications to adapt.	Materials technology or its associated development may find limited application in non-aerospace civil sectors.
4	Materials technology or its associated development is expected to create strong impact and may lead to technological breakthroughs.	Materials technology or its associated development is suitable for land, air, and sea platforms and endures harsh environments such as heat,and radiation.	Materials technology or its associated development is widely applicable in defense and civil aerospace, and in one additional non-aerospace sector (e.g., energy, automotive).

Table 7. (continued)

5	Materials technology or its associated development can radically transform existing technologies and be central to future innovations.	Materials technology or its associated development demonstrates highly versatile, suitable for use across different engineering disciplines and extreme operational	Materials technology or its associated development has significant applicability across defense, civil aerospace, and most non-aerospace sectors.

		environments with high performance.	

Source: Author

These carefully crafted verbal-labeled Likert-type scales helped reduce ambiguity, supported more consistent judgments across participants, and ensured alignment between the qualitative intent and the quantitative data collected. The use of verbal-labeled Likert-type scales is supported in the foresight literature as an effective technique to facilitate structured expert evaluation (Hines, 2008; A. Salo et al., 2003).

Once all foresight statements were scored individually by participants according to the three evaluation criteria, I proceeded to calculate the node scores[3], defined as the weighted sum of participant ratings across the three criteria, and subsequently the path scores, following a structured multi-criteria decision-making logic. My goal in this phase was to establish a transparent and repeatable method for identifying the most strategically valuable future path.

3.4.3.1. Node Scoring Formula

Each foresight statement (or "node") received three separate ratings, one for each evaluation criterion. These ratings were then multiplied by the corresponding AHP-derived weights. I used a summation format in the node score formula to reflect the additive contribution of all three criteria: impact on the future, operational applicability, and dual-use potential. Together, these dimensions define the relevance of each statement. The final node score was calculated as the weighted sum of these three components.

[3] For definition and calculation of Node Score, see Equation 8 below.

The formula used was as follows:

$$\textbf{Node Score} = (P_1 \times W_1) + (P_2 \times W_2) + (P_3 \times W_3) \quad (8)$$

Where:

- P_1, P_2, P_3 are the participant's ratings for the three criteria.
- W_1, W_2, W_3 are the AHP-derived weights for each criterion.
- The output is a single score for each foresight node.

This approach ensured that each foresight statement's score reflected not just participant opinion but also the relative strategic importance of the criteria as defined earlier in the AHP phase.

3.4.3.2. Temporal Weighting

Since this research is based on a foresight approach, I aimed to emphasize the significance of long-term outcomes, which are often more transformative yet less immediately visible. To reflect the increasing strategic value of long-term outcomes, I also introduced an alternative time-weighted scoring model, assigning differentiated weights to nodes based on their temporal layer:

- Short-term node × 0.2
- Mid-term node × 0.3
- Long-term node × 0.5

The time-adjusted path score formula became:

Weighted Path Score:

$$\sum_{t\epsilon\{short,medium,long\}} (Node\ Score_t \times Time\ Weight_t) \quad (9)$$

This time weighted path score represented the final prioritization value for each scenario path. By applying differentiated weights across temporal layers, the scoring model allowed me to highlight future pathways that may be less immediate but more

strategically significant in the long run. All scenario paths were ultimately ranked based on their total time-weighted scores, and the path with the highest score was selected as the prioritized future, forming the basis for the subsequent backcasting phase of the study.

3.4.4. Futures Wheel Focus Group (Implementation Phase)

To collect foresight data for scenario development to see alternative futures related to honeycomb material technology development, I conducted a structured focus group session based on the previously developed Futures Wheel framework. The session was conducted online via Microsoft Teams, lasted approximately 120 minutes, and was audio recorded for analysis purposes, following participants' informed consent. I selected online format because it allowed me to bring together participants from different institutions without logistical constraints and to present the website specifically designed for the focus group clearly, while guiding participants step-by-step through the multi-phase evaluation process using screen-sharing functionalities. A total of 10 participants joined the session, selected for their expertise in defense technologies, aerospace materials, and innovation policy. I aimed to ensure balanced representation across academia, industry, and government (the Triple Helix model), and invited stakeholders accordingly. In addition, the focus group included five female and five male participants, ensuring a balanced gender distribution. Although I made specific efforts to secure participation from all sectors, several invitees, particularly from academia and government, were unable to attend. As a result, the final group was more heavily composed of industry representatives. To ensure the methodological robustness of the session, I did not rely solely on institutional affiliation to achieve representational balance. Instead, I focused on assembling a group with a broad range of disciplinary backgrounds and functional roles. Throughout the session, I employed a moderation approach to support active participation and ensure that each perspective, whether technical, strategic, or academic, was equally integrated into the discussion. In line with Bloor et al. (2001) recommendations for managing participant imbalances in expert-focused settings, I made a deliberate effort to maintain dialogic balance, promote cross-sectoral dialogue, and ensure that diverse perspectives were systematically captured and integrated into the scenario-building process. In

facilitating the session, I was accompanied by a co-facilitator who was well-acquainted with both the foresight methods employed and the online "Futures Wheel" platform. This collaboration contributed to a smoother process, as the facilitator assisted in managing the digital tools and supporting participant interaction throughout the session. The participant profile is shown in Table 8.

Table 8. Futures Wheel Participant Profile Overview

Participant Code	**Title**	**Sectoral Affiliation**	**Specialization/ Focus Area**	**Gender**
P 1	Policy Strategist	Government	National defense policy & strategic planning	Female
P 2	Tech Entrepreneur	Startup	Innovation & technology related to Materials Technology	Male
P 3	R&D Strategist	Materials Industry	Materials Engineering	Male
P 4	Academic-Industry Integrator	Defense & Aerospace Industry	Materials Engineering applications	Male
P 5	System Design Engineer	Defense & Aerospace Industry	Structural design development	Male
P 6	Early-Career Engineer	Defense & Aerospace Industry	Mechanical/structural applications	Female
P 7	Researcher	Academia	Honeycomb structures, additive manufacturing	Female
P 8	Composite Materials Specialist	Defense & Aerospace Industry	Chemical processing, composite materials	Female

Table 8. (continued)

P 9	Manufacturing Specialist	Defense & Aerospace Industry	Materials manufacturing, quality control	Male

P 10	Faculty Member	Academia	Advanced Composites Materials	Female

Source: Author

Before the session, all participants were informed in advance about the structure and objectives of the focus group. An information package was shared via email, which included a user manual explaining how to navigate the custom-designed web platform, an overview introduction to the Futures Wheel method and its application within this research. The purpose of this preparatory material was to ensure that participants arrived at the session with a solid understanding of both the technical aspects of the exercise and the broader strategic importance of their contributions. They were explicitly informed that the insights they would provide would directly feed into the evaluation and prioritization of alternative future scenarios related to honeycomb materials technologies. This early communication also served to establish common ground among participants with varied disciplinary backgrounds, allowing for a more focused and effective engagement during the session.

After the introductory warm-up and methodological briefing, participants individually accessed the custom-designed web interface, where they encountered the first interactive screen (Figure 7) initiating the Analytic Hierarchy Process (AHP) phase. In this step, they were asked to make pairwise comparisons between the three predefined evaluation criteria—Impact on the Future, Operational Application Areas, and Dual-Use Potential—by using a slider-based interface that allowed them to express both the direction and degree of importance on a standard 1-to-9 AHP scale. Each comparison was accompanied by descriptive explanations to support clarity and consistency, and participants were expected to base their inputs on their professional judgment regarding the strategic relevance of each criterion. The system automatically calculated the consistency ratio (CR) for each participant's responses, and the "Karşılaştırmaları Onayla ve Devam Et (Confirm Comparisons and Continue)" button remained inactive unless the comparisons met the required logical consistency threshold, ensuring the reliability and analytical soundness of the resulting weights.

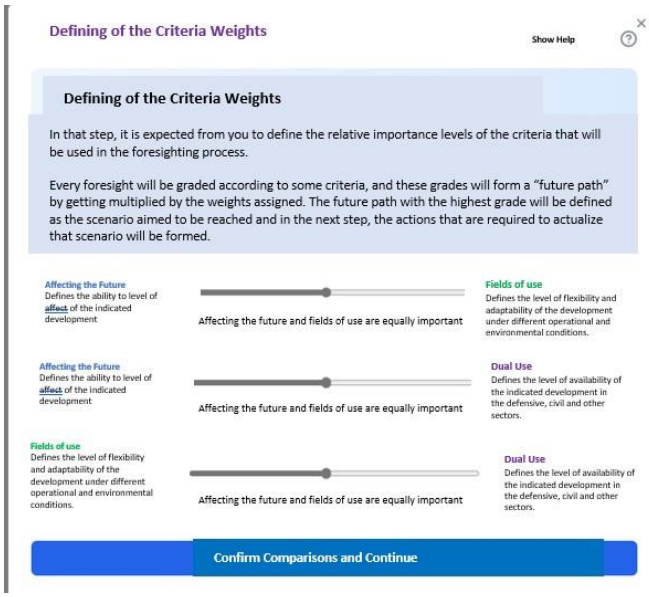


Figure 7. Interface for Pairwise Comparison of Evaluation Criteria (AHP Input Screen)

Source: Author

After completing the AHP-based weighting process, I directed participants to the main interface of the Futures Wheel, which served as thse central workspace throughout the session Figure 8.

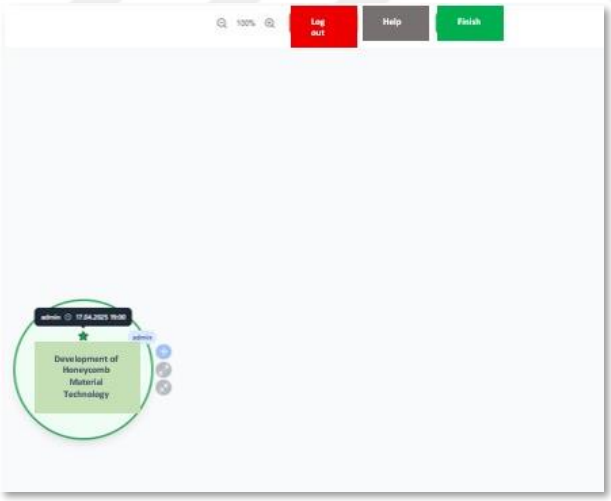


Figure 8. Central Node Interface

Source: Author

This interactive web page presented the core foresight topic: "Development of Honeycomb Material Technologies" as the central node. At this stage, I introduced the interface structure and explained that their foresight inputs would be mapped around this node across three temporal layers: short-term, mid-term, and long-term. Each layer

followed the same process. To begin the short-term layer, I posed the following guiding question to the participants: “What kinds of developments do you foresee in honeycomb material technologies that could happen in the short term?” I then gave participants 10 minutes to reflect individually and enter their foresight inputs directly into the system.

For each input (node), participants were required to write a short foresight statement and evaluate it using the same three criteria introduced earlier: Impact on the Future, Operational Application Areas, and Dual-Use Potential. These evaluations were done using 5-point Likert-type sliders integrated into the entry interface shown in Figure 7. Each time a participant initiated a new entry, the interface shown in Figure 9 opened. This design ensured that each foresight statement was accompanied by structured, criteria-based assessments, which were necessary for the scoring and prioritization stages that followed. To support clarity during the entry phase, I provided real-time guidance and answered any questions through verbal instructions.

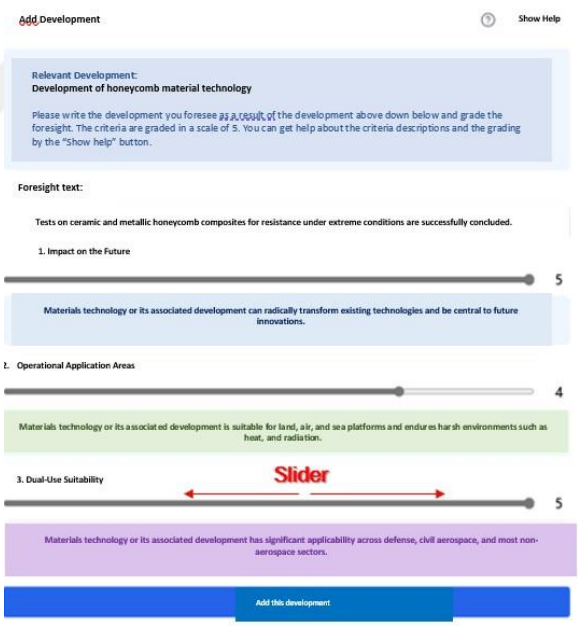


Figure 9. Participant Interface for Entering and Rating a Foresight Statement

Source: Author

After the individual entry phase, I facilitated a 15-minute group discussion where participants reflected on their own and others’ foresight inputs. During this discussion, I encouraged participants to elaborate on their entries, share perspectives, and challenge or support one another’s ideas.

I repeated this procedure in the same format for the mid-term and long-term phases, each time beginning with a time-specific question and proceeding through individual input followed by collective discussion.

I proceeded with the same structure for the mid-term foresight phase. Participants were asked to consider how the developments they or others had proposed might evolve over a longer timeframe. Participants selected an existing short-term foresight statement they found relevant and meaningful and then contributed a corresponding mid-term development that could logically follow from it. This approach encouraged continuity, while also allowing participants to branch out from their own or others' ideas. Each mid-term entry was again evaluated using the same three criteria, Impact on the Future, Operational Application, and Dual-Use Potential, on a 5-point Likert-type scale.

Once all mid-term entries were submitted in ten minutes, I initiated a group discussion, encouraging participants to reflect on the potential transitions between short-term and mid-term developments, and to critically assess whether the projected path appeared plausible, strategically significant, or in need of revision.
The same process was repeated for the long-term foresight phase. Participants reviewed the previously constructed mid-term entries and identified which of these could serve as a foundation for further long-term development. Using this method, participants built future pathways consisting of connected foresight statements across three temporal layers. As with the previous stages, each long-term entry was individually rated against the same set of criteria.

By the end of this stepwise process, a set of interlinked future paths was formed, An example path shown in Figure 10, which demonstrates how sequential foresight inputs in futures wheel form.

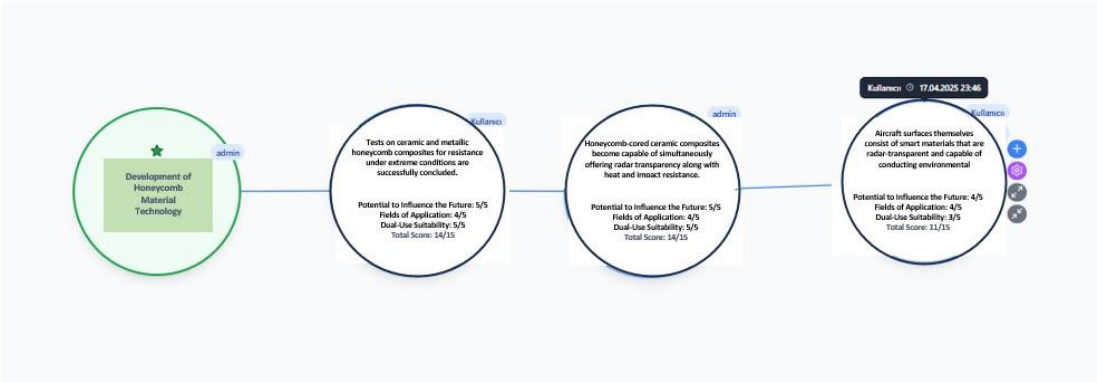


Figure 10. Example Scenario Path Created through the Futures Wheel
Source: Author

Participants responded positively to the structure of the Futures Wheel focus group, especially highlighting the usefulness of the custom website tailored to the method. The visual, step-by-step design helped them articulate ideas clearly, while the custom-designed online platform enhanced engagement by enabling intuitive input and real-time evaluation. Its integrated interface supported seamless navigation and contributed to a smooth scenario-building process.

I observed active participation throughout, with individuals not only contributing insights but also building on each other's inputs. This observation aligns with Spaniol (2024) argument that participatory foresight tools with visual interfaces increase expert engagement and improve the quality of scenario outputs. Embedding evaluation criteria into the interface reduced cognitive load and improved consistency. Overall, the platform supported data collection and provided foresight inputs directly usable in the next research phases.

Following the focus group, I analyzed the foresight statements collected through the platform and calculated the scores of each node based on the pre-defined criteria and AHP-derived weights. I then aggregated these node scores into full scenario pathways across short-, mid-, and long-term layers. By applying the time-weighted scoring model described earlier, I identified the most strategically significant future path. This prioritized path served as a concrete output of the exploratory foresight phase and provided the basis for the subsequent backcasting focus group.

3.4.5. Backcasting Focus Group

To complement the exploratory foresight phase and address the second research question that is “What policies are needed to enable the realization of this prioritized future?” I conducted a second focus group session using the Backcasting methodology. This normative foresight tool enabled participants to envision the conditions and actions necessary to reach the prioritized future scenario identified through the earlier Futures Wheel analysis and scoring.

To ensure continuity between the two foresight phases, I invited the participants from the previous Futures Wheel session to join the backcasting workshop. In order to maintain diversity and enrich the discussion, additional invitations were extended to academics and experts in materials and defense technologies. Unfortunately, due to time constraints, these individuals were also unable to join. Nevertheless, the group was successfully supplemented by one new participant (P 11), a research and development engineer with expertise in patent analysis and materials science. His contribution was particularly valuable in contextualizing technological developments and identifying realistic pathways aligned with ongoing innovation trends. However, four of the earlier participants were unable to attend due to scheduling conflicts. The final composition of the backcasting focus group included seven participants, consisting of six returning individuals (P 1, P 4, P 5, P 6, P 9, P 10) and one new member (P 11). An overview of the participants and their professional profiles is presented in Table 9. With respect to gender distribution, the group included three female and four male participants, reflecting a nearly balanced representation.

Table 9. Backcasting Focus Group Participants

Participant Code	Title	Sectoral Affiliation	Specialization/ Focus Area	Gender
P 1	Policy Strategist	Government	National defense policy & strategic planning	Female
P 4	Academic-Industry Integrator	Defense & Aerospace Industry	Materials Engineering applications	Male

Table 9. (continued)

P 5	System Design Engineer	Defense & Aerospace Industry	Structural design development	Male
P 6	Early-Career Engineer	Defense & Aerospace Industry	Mechanical/structural applications	Female
P 9	Manufacturing Specialist	Defense & Aerospace Industry	Materials manufacturing, quality control	Male
P 10	Faculty Member	Academia	Advanced Composites Materials	Female
P 11	Patent analysis engineer	Defense & Aerospace Industry	Materials science background	Male

Source: Author

The session was conducted online via Microsoft Teams, lasted approximately 120 minutes, and was audio recorded for analysis purposes, following participants' informed consent. For collaborative input and visualization, I utilized the Miro digital whiteboard platform, which allowed participants to structure their ideas interactively. To support participant preparedness and facilitate effective engagement, I sent a preparatory information package. This package included a user guide for navigating the Miro platform and a brief overview of the Backcasting process. I was also supported by a facilitator who was familiar with both the foresight methods applied and the technical functionalities of the digital platforms used. Just like in the Futures Wheel focus group, I again paid particular attention to maintaining dialogic balance and encouraging diverse participation, drawing on Bloor et al. (2001) moderation techniques to ensure that a range of perspectives was actively integrated into the discussion.

I began by introducing the prioritized future scenario to reactivate participants' engagement and establish a shared conceptual baseline. In the initial phase, the goal was to explore participants' perceptions of the envisioned future's strategic significance, particularly in terms of its potential value and relevance for the defense

and aerospace sectors. This included examining how such a future might address sectoral challenges, enhance competitiveness, and contribute to long-term national capabilities. Understanding these perspectives helped me assess participants' alignment with the scenario and provided an entry point for deeper reflection.

Subsequently, the discussion transitioned into a diagnostic phase aimed at uncovering the present landscape of enabling efforts and systemic obstacles. Here, I sought to collect insights into existing activities or initiatives that already contribute to the realization of the prioritized future. At the same time, participants were encouraged to identify the primary barriers avoiding technological and strategic progress.

To support future-oriented thinking and deepen participant engagement, I introduced an immersive imagination exercise inspired by the experiential foresight approaches discussed by Candy & Dunagan (2017) and Voros (2003). As these authors suggest, such techniques enhance flexible thinking and help participants expand their perceptions of plausible futures and perceived courses of action. In this context, I designed a detailed and interconnected future scenario based on the previously prioritized pathway, aiming to help participants vividly imagine the implications of the envisioned future. I invited them to place themselves within this future setting and to engage with it as if they were living in that world.

In the main Backcasting phase, I asked participants to consider the roles and responsibilities of key actors within the Triple Helix model, government, industry, and academia. I structured the exercise around three distinct action-mapping phases: short-term, medium-term, and long-term. For each phase, I first gave participants 10 minutes for silent ideation, during which they individually entered their responses onto the Miro board. This was followed by a 15-minute open discussion, allowing them to elaborate on their own ideas or engage with others' contributions. I applied this structure consistently across all three-time horizons to enable a coherent and comparable exploration of actions over time. This approach allowed me to encourage balanced participation, capture both written and verbal inputs, and ensure inclusive engagement regardless of individual communication preferences.

The Interview Guide, which outlines the structure and flow of the session, is provided in Appendıx C, while the template of the action-mapping board used in Miro is presented in Appendıx D to illustrate the methodological design.

CHAPTER 4

FINDINGS & DISCUSSION

This thesis compiled and analyzed data obtained through focus group interviews to produce concrete outputs that clarify future technological priorities and inform long-term policy decisions regarding the integration of honeycomb materials into defense and aerospace systems. Two focus group sessions were conducted online, each lasting approximately 120 minutes. These sessions facilitated in-depth discussions among participants and generated valuable qualitative data to support the research objectives.

4.1. Futures Wheel Focus Group Analysis

The Futures Wheel workshop was conducted with approximately 120-minute session with ten active participants, as listed in Table 8. During the session, participants were asked to engage in two main tasks that formed the foundation of the foresight analysis. First, they conducted pairwise comparisons of three predefined criteria—Impact on the Future, Operational Application Areas, and Dual-Use Potential to generate relative weights using the Analytic Hierarchy Process (AHP). This weighting process aimed at capturing the perceived importance of each criterion in evaluating future developments. Second, participants generated foresight statements related to the future of honeycomb materials technologies in a temporal sequence, starting from the short term and progressing step by step toward the long term, and assigned scores to each statement based on the same three criteria. This approach enabled both the articulation of possible futures and the systematic prioritization of those futures through a structured decision-making framework. As a result of the workshop, a total of 52 unique foresight statements were produced. Based on this structured input, the session resulted in the identification of 10 complete future paths,

each composed of linked foresight statements that span from short- and medium-term projections to long-term outcomes. In addition to this, 12 partial paths were formed, consisting of only short- and medium-term projections without a corresponding long-term extension. Furthermore, 4 stand-alone short-term foresight statements were recorded that did not connect to any broader temporal progression.

The final visualization of the Futures Wheel, generated on the web-based platform during the session, is provided in Figure 11 to illustrate the configuration of foresight statements across time horizons. While the figure is not intended for a detailed reading of each individual statement, it aims at demonstrating the volume of input collected during the session, as well as to convey the general architecture and logic of the Futures Wheel methodology applied in this thesis. Here, it is important to recall the definition of a Future Path as employed in this study: a future path is defined as a sequence of foresight statements that span across multiple time horizons, short, medium, and long term, creating a logically connected progression. This structural understanding of future paths is visually presented in Figure 3 of the Methodology section. This initial clustering provided the foundational input for the subsequent prioritization process, which utilized the Weighted Path Score calculation (see Formula 9 in the Methodology section) to identify the most prioritized future.

4.1.1. Evaluation and Aggregation of Criteria Weights

Each participant was asked to conduct pairwise comparisons of the three predefined criteria—Impact on the Future, Operational Application Areas, and Dual-Use Potential—to determine their relative importance in prioritizing foresight statements. This process was facilitated by a custom-designed web interface (see Figure 7 in the Methodology section), which featured a slider-based comparison tool and an automated consistency ratio (CR) check. The system actively prevented submission of inconsistent judgments by disabling the confirmation button and alerting participants until logical consistency was achieved. Additionally, the interface provided real-time verbal explanations of each selected pairwise comparison, which helped participants clearly grasp what their choices meant in relation to one another. This support enabled them to make more informed and consistent decisions.

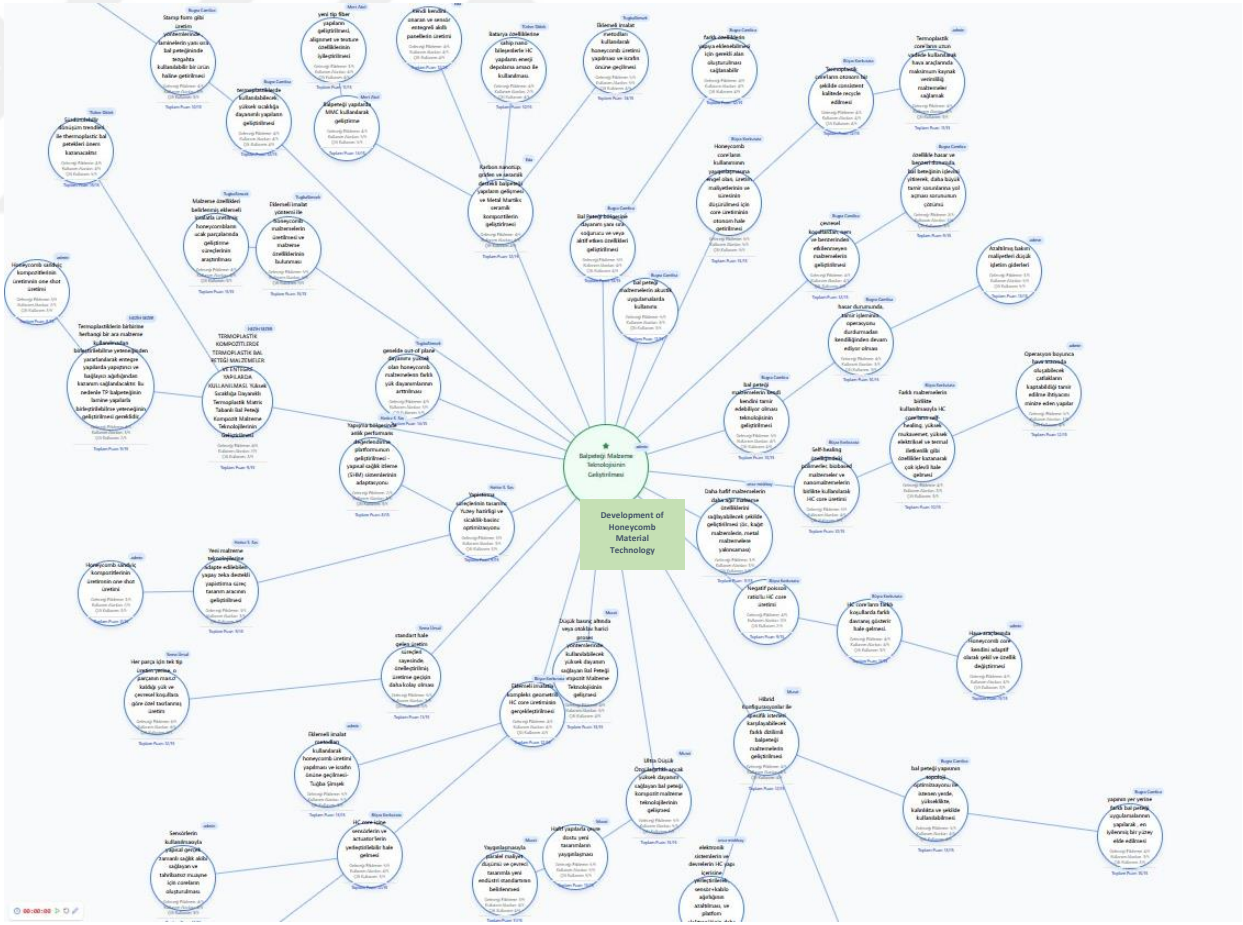


Figure 11. Final interface of the web-based Futures Wheel platform.

Source: Author

The individual weightings derived from these comparisons, along with the aggregated geometric mean and normalized values, are summarized in Table 10.

Table 10. Individual and Aggregated Weights for Criteria

Participant Code	Impact on the Future	Operational Application Areas	Dual-Use Potential
P1	0.13	0.66	0.21
P2	0.31	0.20	0.49
P3	0.55	0.37	0.08
P4	0.16	0.19	0.66
P5	0.57	0.33	0.10
P6	0.12	0.61	0.27
P7	0.48	0.12	0.41
P8	0.33	0.33	0.33
P9	0.38	0.07	0.55
P10	0.19	0.72	0.08
Geometric Mean (6)*	0.28	0.28	0.25
Normalization (7)* Final Weights	0.34	0.35	0.31
*The formulas with associated numbers are provided in the Methodology section, specifically in Part 3.2.2.1.			

Source: Author

A review of the data reveals notable differences in participants' preferences. Firstly, while Impact on the Future received relatively high scores from participants P3, P5, and P7 (0.55, 0.57, and 0.48 respectively), others— P1, P4, and P6 assigned it significantly less importance. Conversely, Operational Application Areas was rated highest by P1, P6 and P10 (ranging from 0.66 to 0.72).

Interestingly, the "Dual-Use Potential" criterion received relatively high ratings from multiple participants namely P2, P4, and P9 (ranging from 0.27 to 0.66), suggesting that considerations of civilian-military applicability may play a central role.

Participant P8 presents a balanced weighting (0.33, 0.33, 0.33), reflecting equal importance across all criteria that likely a result of equal values in the pairwise comparison matrix, which is methodologically valid but analytically limited, as it does not reflect a clear prioritization. In contrast, P10 assigned a clearly higher weight to "Operational Application Areas" (0.72), indicating a strong preference for practical applications. This may reflect an application-oriented perspective shaped by an academic background focused on systems integration or project-based work.

Following individual calculations, the geometric mean was computed across all participants for each criterion, yielding values of 0.28 for both "Impact on the Future" and "Operational Application Areas," and 0.25 for "Dual-Use Potential." These values were then normalized (as described in Formula 7 in Section 3.2.2.1 of the Methodology), resulting in final aggregated weights of 0.34, 0.35, and 0.31, respectively. Although participants expressed differing individual judgments, the aggregation process produced relatively close group-level scores. This convergence does not necessarily indicate full consensus in the behavioral sense but rather reflects the smoothing effect of geometric mean aggregation, which balances out variations in individual input. Such outcomes are common in group AHP studies and are viewed as a methodological feature (Dong et al., 2010; Saaty, 1980, 2008; Saaty & Vargas, 2012). This methodological feature refers to how group AHP reduces variation in individual judgments through geometric mean aggregation. Rather than reflecting true consensus, the resulting convergence is a mathematical outcome of the method. This approach helps produce balanced and interpretable group results even when participants hold differing views. Therefore, the observed closeness in weights should be seen as a product of the aggregation technique, not as uniformity in opinion.

4.1.2. Futures Wheel Prioritization Outcomes and Methodological Discussion

4.1.2.1. Prioritization

After future wheel focus group, a total of ten complete scenario pathways were constructed, each encompassing short-, medium-, and long-term developments. In addition, twelve scenario paths covering only the short- and medium-term, and four

isolated short-term foresight statements were identified. Undoubtedly, each of these foresight statements, alternative futures and scenario suggestions provides valuable input for shaping perspectives on the future (Glenn, 2009; Miller, 2007). However, the methodological framework of this study is specifically designed to prioritize scenario pathways that include the full temporal structure short, medium, and long term to establish a prioritized future scenario. The primary reason for this approach is that it directly aligns with the first research question posed in this thesis that is “What is the prioritized future of honeycomb materials technologies in the defense and aerospace industries?”. Therefore, both the evaluation and scoring processes were conducted exclusively on the ten scenario pathways that fulfilled all three temporal layers. The reported results are limited to these complete pathways to ensure consistency with the research objective.

The ten future paths that included short-, medium-, and long-term foresight statements were scored and ranked based on the Temporal Weighted Path Score formula (9), as presented in Table 11. This table provides an overview of each path’s individual node scores per temporal layer and their cumulative time-weighted score.

As a result of the multi-criteria prioritization analysis conducted in this study, the scenario pathway that received the highest temporal weighted score is identified. This scenario, defined as the "prioritized future," is based on the structural lightweighting applications of honeycomb material technologies. This path is characterized by a sequence of foresight statements progressing through temporal layers;

in the short term, the development of ultra-low specific weight yet high strength composite honeycomb materials technology.
in the medium term, the widespread adoption of environmentally friendly designs;
in the long term, the reduction of costs and the establishment of new industrial standards through the adoption of sustainable honeycomb structures.

Table 11. Prioritized Future Paths Based on Temporal Weighted Path Scores

	Short Term Foresight Statement				Mid Term Foresight Statement				Long-Term Foresight Statement				Total Node Score (8)	Temporal Weighted Path Score (9)
1	Participant	P5			Participant	P5			Participant	P5			13,66	4,33
	Development of ultra-low specific weight yet high-strength honeycomb composite materials				New environmentally friendly designs become widespread with lightweight structures				Cost reduction and the establishment of new industry standards through widespread adoption of sustainable honeycomb structures					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	3,00	4,00	4,00	3,66		
2	Participant	P6			Participant	P6			Participant	P6			12,69	4,05
	Autonomous core manufacturing to reduce production time and cost, removing a key barrier to honeycomb core adoption				Recycling of thermoplastic cores with consistent quality via autonomous systems				Use of thermoplastic cores to maximize resource efficiency in aerospace applications					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	5,00	5,00	5,00	5,00	4,00	4,00	4,00	4,00	4,00	4,00	3,00	3,69		
3 (tie)- Future Path 3	Participant	P1			Participant	P3			Participant	P3			12,31	4,03
	Development of honeycomb structures supported by carbon nanotubes, graphene, ceramics, and metal matrix composites				Integration of MMC (metal matrix composites) into honeycomb structures				Development of new fiber architectures with enhanced alignment and surface texture control					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	4,00	4,00	4,00	4,00	4,00	5,00	5,00	4,66	3,00	4,00	4,00	3,66		
3(tie)- Future Path 4	Participant	P4			Participant	P4			Participant	P4			12,00	4,03
	Development of self-healing honeycomb materials to improve structural resilience				Damage repair processes that continue autonomously without interrupting operations				Damage repair processes that continue autonomously without interrupting operations					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	5,00	4,00	4,00	4,34	4,00	3,00	3,00	3,34	3,00	5,00	5,00	4,31		

Source: Author

Table 11. (continued)

	Short Term Foresight Statement				Mid Term Foresight Statement				Long-Term Foresight Statement				Total Node Score (8)	Temporal Weighted Path Score (9)
5	Participant	P5			Participant	P2			Participant	P2			11,69	3,98
	Development of hybrid-configured honeycomb structures to meet specific functional requirements				Integration of electronic systems within honeycomb cores to reduce sensor/cable weight and improve platform efficiency				Creation of a system that knows the computer-supported position better if the electronics work in an integrated way in honeycombs and is integrated into the platform itself in its circuits					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	4,00	4,00	4,00	4,00	3,00	4,00	3,00	3,35	5,00	4,00	4,00	4,34		
6	Participant	P6			Participant	P6			Participant	P6			11,73	3,86
	Realisation of complex geometry HC core production by additive manufacturing				Integration of sensors and actuators into honeycomb cores				Structural health monitoring-enabled smart cores with real-time diagnostics and non-destructive inspection capabilities					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	4,00	4,00	4,00	4,00	5,00	4,00	3,00	4,04	4,00	4,00	3,00	3,69		
7	Participant	P6			Participant	P6			Participant	P6			11,37	3,81
	HC core production using self-healing polymers, biobased materials and nanomaterials in combination				Combining materials to create ***multi-functional cores*** with self-healing, high strength, and electrical/thermal conductivity				Aircraft structures capable of autonomously healing cracks during operation.					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	5,00	4,00	3,00	4,04	4,00	3,00	3,00	3,34	5,00	3,00	4,00	3,99		
8	Participant	P5			Participant	P4			Participant	P4			11,69	3,77
	Development of hybrid-configured honeycomb structures to meet specific functional requirements				The honeycomb structure can be used in the desired location, height, thickness and shape with topology optimisation				Customized surface-enhanced honeycomb implementations replacing traditional structures					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	4,00	4,00	4,00	4,00	5,00	4,00	4,00	4,34	4,00	3,00	3,00	3,34		
9	Participant	P6			Participant	P6			Participant	P6			10,42	3,56
	Production of honeycomb cores with negative Poisson's ratio (i.e., when Poisson's ratio is negative, materials contract inward rather than expanding outward when compressed. The opposite of most materials)				Different behaviour of HC cores under different conditions				Adaptive cores in aircraft that change shape and properties dynamically					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	4,00	3,00	2,00	3,04	4,00	4,00	3,00	3,69	4,00	4,00	3,00	3,69		
10	Participant	P9			Participant	P9			Participant	P10			8,68	2,83
	Use of thermoplastic matrix-based honeycomb composites in integrated high-temperature structures				By utilising the ability of thermoplastics to be joined to each other without using any intermediate material, adhesive and binder weight will be saved in integrated structures. Therefore, it is necessary to improve the ability of TP honeycomb to be combined with laminated structures				One-shot production of honeycomb sandwich composites (i.e., producing the entire layered structure in a single manufacturing step, instead of assembling it in multiple stages					
Score	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**	**Impact on the Future**	**Operational Application Areas**	**Dual-Use Potential**	**Node Score**		
	4,00	2,00	3,00	2,99	4,00	3,00	2,00	3,04	3,00	2,00	3,00	2,65		

One plausible explanation for why this pathway ranked first may lie in the fact that the concept of lightweighting carries important implications for the defense and aerospace sectors. The most important benefit of lightweight structures is their ability to reduce fuel consumption, thereby improving operational efficiency. This directly contributes to logistical advantages and aligns with broader sustainability (Bitzer, 1997; Qi et al., 2021). In particular, lightweight composite structures used in aircraft fuselages and space vehicles increase mission range and optimize payload capacity (Babus et al., 2004).

A particularly notable aspect of this path is its strong alignment with the historical factors behind the development of honeycomb structures, namely, the balance between low weight and high mechanical strength. Rather than radically transforming the core technology, the foresight statements in this path aim to extend and enhance its original strengths. This suggests that technological improvements in material technologies do not always require radical transformation; in some cases, major progress can be achieved by building on a material's fundamental strengths. As Bitzer (1997) and Romanowski and Nadolny (2018) emphasize, honeycomb structures have long been valued for their ability to combine mechanical strength with low weight, a property that has established their strategic importance in both defense and aerospace domains. This remains highly relevant today, and instead of replacing it with new approaches, improving and building on its core strengths is often more effective. In this sense, continuing to develop honeycomb technologies in alignment with their original advantages represents a logical and sustainable path forward in the evolving landscape of advanced materials. Furthermore, the foresight elements within this pathway do not merely focus on materials technology but also foresee sectoral transformation in terms of environmental impact, cost efficiency, and regulatory alignment. Indeed, sustainable materials technologies contribute not only to compliance with environmental standards but also to increased supply chain resilience and the expansion of dual-use potential across military and civilian domains (Sarjito, 2024). In particular, the long-term foresight statement referring to the "establishment of new industry standards" indicates a structural transformation that could influence the entire value chain as these technologies become mainstream.

While the prioritization scores point to a clear leading future path, a closer analysis of the remaining paths reveals several important insights. For example, although the third and fourth scenario pathways received the same temporal weighted path score, this outcome illustrates how the time-weighted scoring system can occasionally act as a structural equalizer. Even when the node scores vary in weight across different time layers, the aggregated score may still appear similar. When two pathways receive identical temporal scores, just like here, distinguishing between them can be challenging. In such cases, using an alternative evaluation criterion such as the total node score can offer a practical resolution. Indeed, in this study, the relative ranking of the third and fourth future paths was determined based on their total node scores. This approach can maintain the methodological value of temporal weighting while demonstrating that total node score can serve as a complementary criterion when necessary.

While identical scores may require such supplementary strategies, Total Node Scores and Temporal Weighted Path Scores showed strong alignment in the first and second scenario pathways, demonstrating the internal consistency of the evaluation framework. This consistency indicates that the scenarios rated most impactful, applicable, and open to dual use by participants were also considered strategically valuable in the long term. As a result, a natural convergence between Total Node Scores and Temporal Weighted Path Scores emerged, highlighting the overall consistency and reliability of the evaluation process.

A deeper review also reveals how similar core technologies may be strategically positioned for different objectives. For instance, both the fourth and seventh scenario pathways are centered on self-healing honeycomb structures, yet they differ significantly in purpose. The fourth scenario emphasizes structural resilience, aiming to ensure operational continuity and durability in defense and aerospace systems. The seventh scenario, by contrast, treats self-healing not only as a protective mechanism but also to achieve multifunctionality, integrating properties such as electrical and thermal conductivity and enhanced mechanical performance. These differing perspectives illustrate how single enabling technology can be tailored to meet varying goals.

The foresight statements produced during the study appear to cluster around three major thematic domains: material development, production processes, and functional integration. Within the material development domain, efforts are primarily aimed at modifying the structural properties of honeycomb materials through the incorporation of advanced material types. These include nano-enhanced components, biobased materials, and thermoplastics. A closer look reveals the integration of next-generation substances such as carbon nanotubes, graphene, metal matrix composites, and sustainable polymers into honeycomb configurations. This approach not only targets enhanced mechanical performance but also aims to achieve goals related to weight reduction, environmental compatibility, and recyclability. The production process domain focuses on improvements in manufacturing techniques. Key foresight elements in this category include additive manufacturing (3D printing), surface preparation innovations, and bonding methods that eliminate the need for adhesives. These developments are expected to yield significant operational advantages, particularly in terms of productivity and cost efficiency. Finally, the functional integration domain highlights a shift in the role of honeycomb materials from being merely passive structural components to becoming active, intelligent elements within larger systems. In this context, self-healing capabilities, integrated sensor systems, and structural health monitoring features emerge as key improvement areas. These technologies are designed to enhance system-level performance, enabling materials to participate in real-time diagnostics and adaptive functionalities.

During the focus group sessions, I observed that participants interpreted the concept of "honeycomb" in different ways. Some participants approached it as a structural system, while others emphasized its functional attributes or associated manufacturing processes. This diversity reflects the multidimensional nature of honeycomb structures and their applicability across different contexts. However, in this thesis, honeycomb structures are conceptually framed as a material technology to ensure consistency and coherence throughout the analysis. This framing encompasses not only the physical form of the structure but also its composition, production methods, and functional integration. All foresight statements generated during the process have been analyzed within this conceptual framework, and the participants' contributions align well with this perspective.

4.1.2.2. Methodological insights

Beyond the thematic, technological, and prioritization-related findings, the workshop process revealed several methodological dynamics referring here to the patterns of interaction, participant behavior, and interpretive approaches that unfolded during the foresight exercises. Since foresight exercises rely heavily on interaction among participants, analyzing these dynamics is essential for understanding how knowledge is co-produced and how scenario thinking is collaboratively constructed. These dynamics offer valuable insights into how participants engaged with the process and how collective futures were shaped.

The application of the Futures Wheel method in this study not only supported the generation of individual foresight statements but also fostered interactive idea development among participants. During the workshop process, several foresight items were initially introduced by one participant and later extended through medium- and long-term developments by others. For instance, in the third future path, the short-term foresight statement was proposed by Participant P1, while the medium- and long-term extensions were developed by Participant P3. This clearly demonstrates how individual contributions evolved into collectively constructed. This dynamic illustrates the method's inherently collaborative nature and its ability to support shared thinking processes. The structure of interaction observed among participants closely aligns with key principles in foresight literature, particularly those emphasizing knowledge exchange and the co-creation of strategic narratives. Both the methodological setup and the digital interface used during the sessions contributed to enabling this interaction by allowing participants to build on each other's inputs in real time. As Milojević & Inayatullah, (2015) also highlight, the process of constructing future-oriented narratives through active participant engagement plays a vital role in shaping collective visions of the future.

Another important observation from the analysis relates to how, in certain cases, some short-term foresight statements were independently extended into different medium-term developments by different participants. This was particularly evident in the fifth and eighth future paths, where participants began from same short-term foresight

statement but envisioned divergent directions as the scenarios evolved. For instance, in both pathways, Participant P5 introduced the foresight statement “development of hybrid-configured honeycomb structures to meet specific functional requirements.” In the fifth pathway, Participant P2 continued this trajectory toward electronic integration, focusing on embedding electronic systems within the honeycomb core. In the eighth pathway, Participant P4 extended the same short-term idea in a different direction, emphasizing topology optimization and customized structural configurations. While this was not observed across all scenario paths, these cases highlight how foresight statements can function as flexible starting points, interpreted and expanded in different ways depending on the participant's perspective. This illustrates that foresight statements are not fixed or linear constructs; rather, they are dynamic and multi-directional, shaped by the unique perspectives of each participant (Kok et al., 2011; Linturi et al., 2022). This phenomenon is often interpreted as the result of differing individual expertise and sectoral positioning, which can lead to multiple future visions emerging from the same technological trigger (Glenn, 2009). In other words, a short-term technological signal may be understood by one participant as a call for electronic integration, while another may interpret it in terms of structural customization or production process improvement. Even the same starting point can lead to different future paths depending on how it is interpreted by expert perspectives.

Further observation from the workshops concerned the varying levels of depth and technical detail found in the foresight statements. Some foresight statements included advanced engineering concepts and system-level integration, such as “structural health monitoring-enabled smart cores with real-time diagnostics.” Others, by contrast, remained more general and strategically oriented, like “aircraft structures capable of autonomously healing cracks.” This diversity illustrates that the methodology used in this study was sufficiently flexible to enable participants to contribute from their own domain knowledge and positional understanding, allowing for a wide range of unique viewpoints. Such variation contributes to the nature of the foresight process, and it enriches the quality and multidimensionality of the resulting outputs. These differences were not only technical in nature but also reflected the varying impact domains addressed by the foresight statements. While some participants focused on material engineering, manufacturing techniques, or structural design (for example,

“development of new fiber architectures with enhanced alignment and surface texture control”, others addressed broader systemic implications such as economic impact, industrial norms, or policy transitions. One such example is the statement “cost reduction and the establishment of new industry standards through widespread adoption of sustainable honeycomb structures.” These findings show the potential of foresight methodologies to address not only the question “what kinds of technologies might emerge,” but also “what kinds of systemic transformations might those technologies enable.” In this regard, the diversity of the participant group including experts from industry, government, and academia proved methodologically valuable, offering both analytical richness and the basis for a multidimensional interpretation of future scenarios.

In terms of gender distribution, while no fundamental divergence in foresight judgments emerged along gender lines, some nuanced differences were observed. Female participants tended to emphasize operational applicability and integration into existing defense systems, whereas male participants placed slightly greater weight on long-term technological potential and dual-use opportunities.

In summary, the Futures Wheel analysis conducted in this study generated a rich and multi-layered set of foresight statements and scenario pathways concerning the future of honeycomb material technologies in defense and aerospace. Through a structured methodology involving both criteria weighting and temporal prioritization, ten comprehensive future paths were identified and evaluated, culminating in the selection of a prioritized future scenario centered on lightweighting applications. Beyond the numerical prioritization, the process revealed key thematic domains such as material innovation, production processes, and functional integration while also highlighting the collaborative and multi-perspective nature of foresight construction. The methodological flexibility of the Futures Wheel enabled diverse technical and strategic contributions, underscoring the value of expert heterogeneity in shaping robust and nuanced visions of the future. This participatory approach not only offered insights into emerging technologies but also captured the systemic transformations they may catalyze.

4.2. Backcasting Focus Group Analysis

This section presents the findings of the second focus group conducted using the Backcasting method, designed to address the second research question: What types of policy interventions are necessary to enable the realization of the prioritized future scenario identified through foresight? This scenario, previously developed through the Futures Wheel and scoring process, outlines a progressive pathway characterized by three temporal layers: in the short term, the development of ultra-low specific weight yet high-strength composite honeycomb materials technology; in the medium term, the widespread adoption of environmentally friendly designs; and in the long term, the reduction of costs and the establishment of new industrial standards through the adoption of sustainable honeycomb structures. The Backcasting session was structured to work backward from this desired future, encouraging participants to articulate necessary enabling actions in temporally sequenced manner.

The qualitative data generated during this session were analyzed using Reflexive Thematic Analysis (RTA) in MAXQDA, following an inductive coding approach. More than 80 coded segments were identified, emerging directly from the participants' own expressions rather than a predefined framework. The code book is given in Figure 12. These insights came from both the written content on the Miro digital whiteboard where participants recorded their ideas during the initial 10-minute silent ideation phase and from verbal contributions made during the subsequent open discussion.

When participants shared actionable ideas verbally without noting them down, either the moderator or the facilitator documented these in real time to ensure they were not overlooked in the analysis. This approach allowed for a comprehensive representation of the conversation, capturing both structured inputs and spontaneous reflections. The final version of the Miro board can be found in Appendıx E.

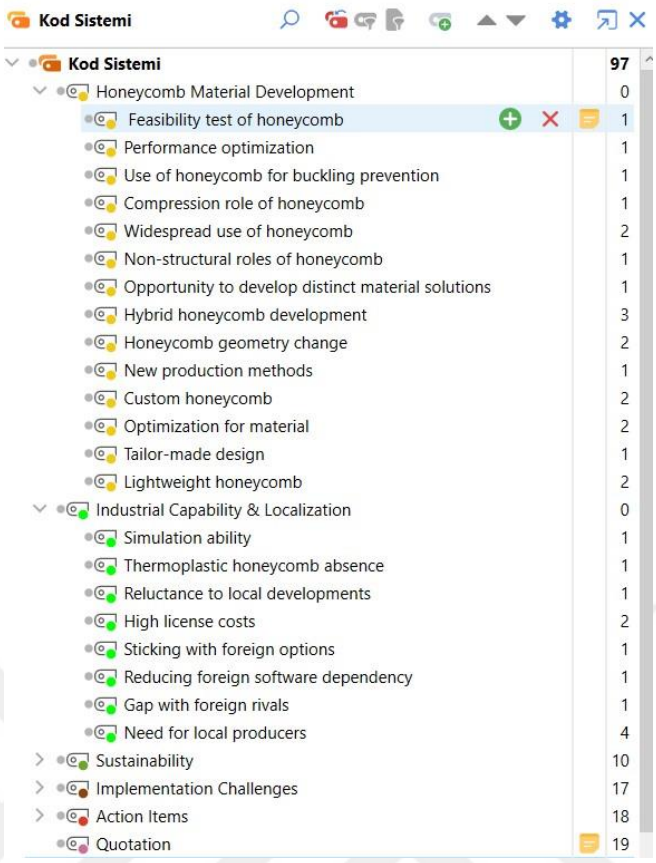


Figure 12. Code System

Source: Author

Rather than presenting the findings through the original theme generated during MAXQDA analysis, I reorganized the insights around four broader titles. These titles were not directly derived from a single theme but emerged through the interpretive synthesis of multiple, thematically distinct but contextually related quotes and codes. In many instances, these categories combined insights from different parts of the discussion that converged around shared concerns or priorities. This structure enabled a more policy-oriented interpretation of the data by emphasizing how diverse viewpoints, when considered collectively, revealed concrete action areas with high potential for policy development. To maintain methodological transparency, each quotation is accompanied by its associated code and theme from the original analysis. While these titles do not correspond to time-based categories used in the scenario planning stage, they provide an integrated structure through which strategic action can be explored. Temporal dimensions are revisited later in the conclusion and policy recommendations.

Although the Backcasting session suggest numerous policy recommendations across a broad spectrum, this analysis specifically focused on four strategically significant areas given below. These areas were chosen for detailed interpretation due to their central importance and the depth of participant discussion, reflecting their potential as foundational pillars for effective policy intervention. The other policy suggestions generated in the session are acknowledged and incorporated into the broader recommendations presented subsequently.

4.2.1. Enhancing Honeycomb Materials Technology

While the development of lightweight yet high-strength composite structures remains a key objective, participants proposed specific design and production strategies that directly contribute to achieving this goal from a technical side. One participant emphasized the early-stage exploration of hybrid honeycomb configurations, noting efforts to experiment with alternative geometries and advanced material combinations. These designs aim to surpass traditional hexagonal patterns and lay the groundwork for more versatile and high-performance structures.

> *"Hybrid honeycomb designs are being studied, not only traditional patterns but also new configurations allowing advanced materials and structures. This is still at an early stage."* (Participant P5, Hybrid honeycomb development, Honeycomb Material Development)

Although these ideas are still largely conceptual, they have already inspired tangible academic actions. A short-term proposal developed through this research suggests launching structured investigations into geometric and topological diversity in honeycomb structures. Specifically through controlled experimentation with cell geometry, orientation, layering, and graded densities.

This type of exploratory work, led by research institutions and supported by public agencies, can form the scientific foundation for long-term composite material capabilities. These statements resonate with broader academic discussions on the evolution of architectured materials as a promising area within materials science. For instance, Fleck et al. (2010) emphasize that structural performance can increasingly be

engineered through geometric architecture rather than purely through material composition. Similarly, Zhang et al. (2020) highlight how non-traditional lattice configurations can deliver enhanced performance under dynamic stress conditions. These insights reinforce the value of advancing beyond conventional hexagonal forms to unlock new possibilities in honeycomb design.

Another participant expanded on this trajectory by advocating for customized, 3D-printed honeycomb structures. Moving away from standard solutions, the participant highlighted the necessity of tailoring cell sizes and wall thicknesses based on operational loads and environmental conditions.

> *"Instead of mass-produced, standard honeycombs, we need 3D-printed, load-specific designs with varying cell sizes and thickness."* (Participant P6, Custom honeycomb, Honeycomb Material Development)

Participant P6's perspective aligns with emerging trends in materials engineering that emphasize application-specific design and manufacturing flexibility. Qi et al. (2021) underscore the growing significance of 3D printing also known as additive manufacturing (AM) in facilitating geometry-driven material innovation, especially in aerospace contexts where design constraints are stringent. AM enables topological optimization distributing material only where structurally necessary—to enhance both performance and efficiency (Seharing et al., 2020). Singh et al. (2024) further highlight that AM allows for the rapid production of custom-designed honeycomb components, contributing to structural performance while also meeting sustainability goals. These developments demonstrate a broader shift from theoretical design variation toward functionally integrated, scalable production pathways.

This developmetns builds upon earlier actions identified in the study particularly those focused on academic research into geometric and topological variation. Rather than repeating those efforts, it suggests a clear next step: shifting from problem identification to long-term, application-oriented development. The participant's focus on customization and operational relevance reflects a broader move toward implementation and scale, aligned with future policy and industrial priorities.

4.2.2. Bridging Research and Application

Composite honeycomb materials particularly those designed for lightweight represent a relatively new technological domain within the national context. As such, their integration is accompanied by a range of implementation challenges. Among these, one of the most significant is the misalignment of goals between academia and industry. This issue was clearly articulated by both a faculty member specializing in advanced composites (Participant P10) and a system design engineer working in defense aerospace systems (Participant P5), who described the structural barriers that hinder effective collaboration and knowledge transfer. While Participant P5 and Participant P10 offered insights into the nature of this gap, Participant P6 contributed to the discussion by proposing mid-term, actionable solutions such as the establishment of Centers of Excellence and the prototyping of research outcomes that aim to bridge the research–application divide and accelerate industrial adoption.

Participant P5, a system design engineer from the defense and aerospace sector, emphasized a fundamental limitation in the industry's engagement with experimental materials. As he noted:

> "*Platform manufacturer companies don't really have the luxury to test many new materials. Of course, we engage in R&D, but our main role is application. Universities are better suited for experimental studies. When industry and academia collaborate, a joint effort is possible. I think we have the capability but perhaps face issues in forming the right partnerships."* (Participant P5, Academia–Industry goal misalignment, Implementation Challenges)

This statement highlights division of functional roles between academia and industry. While universities are expected to lead early-stage experimentation, industrial stakeholders are often constrained by time, cost, and certification pressures, leaving little room for exploratory testing. P5's emphasis on the need for "the right partnerships" points to a structural gap in current collaboration models. This observation aligns with Perkmann et al. (2013), who argue that while academic institutions prioritize novelty and publication, industry partners typically focus on practical implementation and risk mitigation, leading to goal misalignments in collaborative settings.

From the academic side, participant P10 echoed these concerns, drawing attention to the lack of scalability and industrial alignment in academic research:

> "*In academia, we develop lab-scale solutions for specific material goals, like improving impact resistance or buckling. While these are valid for publications, they often do not translate into certified, industrial systems, especially in aerospace."* (Participant P10, Academia–Industry goal misalignment, Implementation Challenges)

This quote underscores the disconnection between academic incentives and industrial requirements. Academic work is often shaped by the logic of publish and laboratory validation, yet lacks the practical pathways for certification and integration. Bruneel et al. (2010) similarly note that structural and cultural differences, such as differing time horizons and output expectations frequently limit the translation of academic research into industrial solutions. As a result, promising innovations may remain trapped at the research stage, failing to reach operational maturity.

Further elaborating on this challenge, P5 added a more nuanced critique:

> "*Solving very specific problems with very specific materials doesn't necessarily lead to scalable, cost-effective industrial solutions."* (Participant P5, Academia–Industry goal misalignment, Implementation Challenges)

It might seem a little frustrating at first, but P5's comment underscores a constructive call to recalibrate academic research toward scalability and cost-effectiveness, fostering much closer academia–industry collaboration.

Later in the focus group, a potential solution to this challenge was suggested as the establishment of Centers of Excellence that could serve as collaborative platforms to bridge the research–application gap. These centers were envisioned as mechanisms to standardize testing processes and foster joint efforts between universities and industry. This suggestion emerged while the participant was discussing middle-term actions that the government should undertake. This suggestion emerged as the participant was expressing a view on what the government could consider as a middle-term action.

> *"Centers of excellence are being planned. These centers could standardize testing and bring together universities and industry for application-driven*

work."
(Participant P6, Collaboration for research & application, Action Items)

This suggestion was coded under the "Action Items" category and presents a system-level response to the misalignment problem. Such centers would not only facilitate joint testing and validation but also serve as neutral hubs for standardization and collaboration across sectors. They could act as intermediary institutions capable of aligning research trajectories with industrial requirements, providing shared infrastructure, and fostering long-term partnerships.
The participant further noted:

> *"Excellence centers can bridge the research–application gap and serve as a hub for standardization and cross-sector collaboration."* (Participant P6, Collaboration for research & application, Action Items)

The role envisioned for these centers aligns with strategic innovation frameworks, which suggest that such institutions can strengthen applied research capacity, support researcher reintegration, and stimulate entrepreneurial discovery through targeted sectoral investment (Terziev & Bogdanova, 2019).

As a middle-term action to be undertaken by industry, Participant P6 also highlighted the importance of prototyping research outcomes as a complementary step to support industrial adoption, and she further pointed out that a well-functioning Center of Excellence could facilitate and accelerate this process.

> *"What we need now are low-density but high-strength honeycomb materials. Such a material doesn't exist yet. That's why we need these materials to be investigated in universities. We did this in the short term — the materials were studied. Now, for these to be widespread, they need to be usable in actual applications. This was also a demand-driven research effort carried out in universities. To enable adoption, we should create a prototype in industry using these results. For instance, a component like a wing — which is commonly used — or the fuselage can be selected. If the tested material from the university is used in producing a prototype, it can become an industrial product. That's how it can be scaled up."*
> (Participant P6, Prototyping the research outcome, Action Items)

This statement of Participant P6 underlines the necessity of demonstrating practical use cases for emerging materials, particularly in the defense and aerospace sectors

where scalability and certification are essential. By proposing a prototype-based approach, P6 identifies a critical mid-step between academic research and industrial integration where validated components can help reduce uncertainty and encourage wider adoption in the field.

In summary, given that honeycomb materials are relatively new to the national context, the collaboration between academia and industry is not only functionally necessary but also strategically important in raising awareness. It reinforces the complementary roles of academia in discovery and of industry in application, underlining the need for mutual recognition and coordinated action. Importantly, proposed actions such as the establishment of Centers of Excellence and prototyping of research outputs point to mid-term, actionable solutions. These suggestions reflect a shared recognition among stakeholders that institutional coordination, demonstration-driven innovation, and infrastructure development are essential for translating materials research into certified, functional aerospace applications.

4.2.3. Indigenous Capability Development

Participant P4 emphasized a significant gap in Türkiye's industrial landscape regarding honeycomb materials. He noted that there may be no local firms currently producing honeycomb structures at least not at the required scale and that industrial capability in this area appears limited when compared to standardized, catalog-based production by international firms. This perceived deficiency in indigenous manufacturing capacity not only increases dependency on foreign suppliers but also raises questions about Türkiye's preparedness for integrating ultra-low specific weight yet high-strength composite honeycomb materials technology in strategic sectors like defense and aerospace.

> *"There may not be any local companies producing honeycomb, or at least not at the required scale... I don't think that kind of industrial capability exists in Türkiye."*
>
> (Participant P4, Need for local producers, Industrial Capability & Localization)

In a follow-up remark, the same participant drew attention to a fundamental starting point: understanding domestic demand. Without a clear sense of how much and where honeycomb materials are needed, local production efforts remain directionless. This

view underscores the importance of market-sensing and foresight mechanisms as prerequisites for developing a competitive indigenous industry. These mechanisms ensure that indigenous industry development is not blind or reactionary, but instead informed, targeted, and aligned with strategic goals.

> *"We first need to understand the actual demand for honeycomb structures in Türkiye and then ask: why is no one producing it? Where should we start?"*
> (Participant P4, Need for local producers, Industrial Capability & Localization)

These comments highlight a critical perspective raised during the focus group, although there is clear interest and public investment in developing indigenous capabilities, what is missing is a strong and focused effort to turn these into commercially viable and industrially scalable outcomes. Rather than questioning whether R&D activities exist, the participant draws attention to a deeper issue how these efforts can be transformed into real products and production capacity. This reflects a broader challenge in Turkey's innovation ecosystem: institutional strategies and research programs, including those led by the Presidency of Defense Industries (SSB) given in 2024 OTAĞ report (SSB, 2024) , often remain disconnected from practical implementation. The core problem is not a lack of research, but the difficulty of moving from research results to production and market readiness. In this sense, the participant emphasizes the need to go beyond academic or policy-level initiatives and to build the necessary structures such as demand analysis, prototyping infrastructure, and procurement incentives that can support the actual use and local production of advanced technologies like honeycomb materials.

Implicit in Participant P4's remarks also, consistent with their earlier contributions, is the suggestion that honeycomb materials should indeed be introduced and produced domestically in Türkiye. However, they emphasize that this process should begin with a thorough needs analysis to determine which specific type of honeycomb structure is most in demand. This, in turn, would guide the initial focus of production and ensure that the efforts align with actual indigenous requirements.

This view was complemented by Participant P1, a national policy strategist, who addressed the need for more directive and binding policy tools as a middle-term action to ensure the adoption of indigenous developed technologies within national industrial

platforms. Before explicitly proposing policy enforcement, Participant P1 first drew attention to a persistent reluctance toward indigenous technological developments, even in national-level programs.

> *"R&D projects often stay on the shelf. Even for local platforms, designers may hesitate to use domestically developed systems."* (Participant P1, Reluctance to local developments, Industrial Capability & Localization)

This comment underscores the systemic hesitation to integrate indigenous solutions into platform development, despite ongoing public investments in research and innovation. Importantly, the participant's concern extends not only to university-led R&D but also to outputs developed by newly established firms. In many cases, even when indigenous technologies are available and technically sound, stakeholders tend to avoid their integration driven by a preference for long-established foreign suppliers. In this context, P1 implicitly raised a critical challenge for any new indigenous producer of honeycomb materials. Although such a firm would likely approach the problem through R&D-led innovation, there is no guarantee that its output would be adopted by end-users. This hesitation persists even when the innovation stems from respected academic institutions, making it even more uncertain how a newcomer with no established market presence would be received.

According to P1, earlier efforts to promote adoption through encouragement and incentives have often fallen short. Firms remain reluctant to shift away from familiar sourcing channels, particularly European suppliers. The participant strongly implied that, in the absence of binding mechanisms such as mandatory integration or consequence-based policies. There is little reason to expect voluntary adoption of indigenously developed technologies.

> *"We tried encouragement, but now enforcement might be more effective. If projects aren't implemented, maybe there should be consequences."* (Participant P1, Enforcement Needed, Action Items)

By framing this recommendation within a medium-term, the participant underlined that while short-term investments in research and development are necessary, they must be coupled with systemic regulatory interventions to trigger meaningful

industrial transition. Without this alignment, technological readiness and policy ambitions may fail to translate into real-world outcomes in indigenous capability development.

These observations suggest that domestic honeycomb material production in Türkiye remains largely limited to conventional aramid-based products, and transitioning toward thermoset systems will require not only research but also robust policy support and institutional infrastructure. In this context, the 2024 OTAĞ report by the Presidency of Defense Industries (SSB) provides valuable insight into the evolving R&D landscape. Notably, several sub-technology domains related to honeycomb systems—such as "Honeycomb Glass–Cyanate Ester" and "Honeycomb Aramid–Phenolic"—were newly introduced in the 2024 report under the category of Thermoset Material Technologies, while they were entirely absent in the 2019 version. This inclusion signals a growing institutional interest in next-generation honeycomb technologies, reflecting a strategic recognition of their importance in defense and aerospace applications. However, despite this policy-level orientation, these developments have not yet translated into scalable domestic production.

This gap between strategic intent and implementation underscores a persistent challenge in Türkiye's defense innovation ecosystem that how to ensure that emerging technologies do not remain confined to planning documents or laboratory prototypes. As emphasized in the literature, honeycomb materials are not merely structural components, but integrated technologies whose effective use requires alignment across design, manufacturing, certification, and procurement (Bitzer, 1997; Qi et al., 2021). While the inclusion of honeycomb-related sub-technologies in the 2024 OTAĞ report marks growing institutional interest, it must be supported by a systematic effort to bridge the research–application divide.

Moreover, it is worth noting that thermoset-based honeycomb systems though prominent in policy documents may no longer represent the cutting edge of material innovation. As industry requirements evolve toward multifunctionality, repairability, and sustainability, rigid material categories like traditional thermosets could prove insufficient. This point echoes the discussions in Section 4.2.1, where participants

emphasized the shift toward hybrid geometries, topology-driven material design, and additive manufacturing as the next frontier in honeycomb development. Rather than focusing on predefined material classes, future efforts should prioritize custom-designed architectures that respond to mission-specific performance criteria such as load distribution, environmental resilience, and lightweight optimization.

4.2.4. Advancing Sustainability through Lightweight

The prioritized future, as defined through the backcasting process, envisions a medium-term transition toward environmentally friendly design practices and, in the long term, the establishment of new industrial standards through the widespread adoption of sustainable honeycomb structures. Central to realizing this trajectory is a short-term focus on the development of ultra-lightweight yet high-strength composite materials a foundational step that bridges structural performance with environmental responsibility.

This connection was emphasized by Participant P5 highlighted the contribution of such materials to broader sustainability goals, particularly in the aerospace sector where weight reduction translates directly into fuel efficiency:

> *"Reducing weight via honeycomb structures lowers fuel use and, indirectly, CO_2 emissions."* (Participant P5, Light for less emission, Sustainability)

This comment emphasizes the link between lightweight design and emission reduction, suggesting that even before sustainability becomes a formal design parameter, it can be advanced through material engineering choices. This comment also suggests that, although the use of such materials is not currently a requirement—particularly in the defense sector they nonetheless offer significant sustainability benefits. By integrating environmental considerations into structural performance from the outset, honeycomb technologies inherently support long-term environmental policy goals.

Building on this, Participant P6 drew attention to the evolving use of thermoplastic materials in honeycomb structures highlighting their growing association with sustainability in the field:

> *"Actually, thermoplastic materials are being studied for this. If I'm not mistaken, when we talk about sustainability, one of the first things that comes to mind is thermoplastic materials."* (Participant P6, Environmental friendliness, Sustainability)

However, the growing interest in thermoplastic composites has also revealed a critical industrial gap. Participant P10 highlighted the fact that thermoplastic honeycomb structures are not currently available in the indigenous market like any other honeycomb, which significantly limits their integration into fully sustainable sandwich designs.

> *"There is currently no thermoplastic honeycomb available in the market, despite increased interest in thermoplastic composites. We can't build an entirely thermoplastic sandwich structure due to this gap."* (Participant P10, Thermoplastic honeycomb absence, Industrial Capability & Localization)

This absence not only hinders the realization of environmentally friendly configurations but also reflects a deeper structural weakness in national production capability. Due to that in the short term this participant proposed an action item during the foresight process to initiate academic and industrial collaboration around the development of thermoplastic honeycomb structures focusing on design, compatibility, and benchmarking.

Building on this foundation, Participant P6 suggested that thermoplastic honeycomb structures could become available in the medium term. However, she also noted that recyclability remains a major challenge. Thermoplastics offer potential for both recyclability and lighter weight, but their integration also introduces new implementation challenges. As P6 explained, current difficulties in recycling these materials particularly due to costs and quality constraints limit their widespread adoption:

> *"The recycling of these materials involves certain problems. They are expensive, and it's difficult to recycle them due to the lack of materials with the required quality."* (Participant P6, Recycling constraints, Implementation Challenges)

This reflects a central paradox in sustainable material innovation. Some materials may be labeled "green" in theory yet prove difficult to scale sustainably in practice. The Participant P6 does not stop identifying barriers but proposes a targeted research direction to overcome them:

> *"Actually, the recyclability of polymers could be a topic of academic research. One challenge, for example, is ensuring that the fibers are of the same length and aligned in the same direction. Technologies that can provide this should be explored such as robotic technologies that can cut and place them uniformly."* (Participant P6, Recyclability research need, Action Items)

This insight suggests a mid-term research agenda that moves beyond material selection to process innovation. Rather than viewing recyclability as an external constraint, P6 frames it as a domain for engineering intervention one where robotics, automation, and design precision could enable broader environmental outcomes.

Considering these contributions collectively, these perspectives illustrate how short-term progress in honeycomb material technologies, especially the development of lightweight yet high-strength composites can create pathways toward longer-term sustainability goals. In aerospace, reducing weight is not only a matter of performance, but also a way to lower fuel consumption and carbon emissions. Thermoplastic composites, meanwhile, are seen as promising candidates for combining structural efficiency with environmental responsibility. Yet, their integration also reveals key limitations, from challenges in recycling to the absence of compatible honeycomb cores. Participants emphasized that these gaps particularly the lack of thermoplastic honeycomb production need to be addressed through targeted academic and industrial collaboration. These discussions suggest that sustainability is no longer a distant policy aim, but a guiding principle for both material design and capability development.

CHAPTER 5

CONCLUSION AND POLICY RECOMMENDATIONS

This chapter synthesizes the main findings of the study and presents policy recommendations for advancing honeycomb materials technologies in the defense and aerospace sectors. It is structured in three sections. The first section outlines the research process, including the methodological approach and the main outcomes in relation to the research objectives. The second section provides policy recommendations derived from the foresight results, highlighting their relevance for decision making and implementation. The final section discusses the limitations of the study and offers suggestions for future research.

5.1. Overview Of The Research Process And Main Outcomes

To address the two central research questions, this thesis adopted a sequential mixed-methods approach, combining exploratory and normative foresight methodologies. In response to the first research question “What is the prioritized future of honeycomb materials technologies in the defense and aerospace industries?” a structured foresight process was designed, beginning with a Futures Wheel workshop. The session was conducted as a focus group with ten expert participants from academia, industry, and government, and lasted approximately 120 minutes I used a custom-designed digital platform that I personally developed for this study. Participants generated a total of 52 foresight statements, which were temporally structured into short-, medium-, and long-term layers. From these inputs, 10 complete scenario paths (covering short, medium and long term) were constructed, alongside 12 partial paths (short- and medium-term only) and 4 stand-alone short-term statements. To prioritize the complete scenario paths, a multi-criteria evaluation framework was applied based on three criteria: impact on the future, operational application areas,

and dual-use potential. The Analytic Hierarchy Process (AHP) was used to derive weights for each criterion, and a time-weighted scoring system was employed to account for the increasing strategic relevance of long-term outcomes. As a result of this analysis, a specific scenario path was identified as the prioritized future. This path represents a coherent and feasible trajectory for the advancement of honeycomb materials technologies, characterized by a sequence of developments across time horizons. In the short term, it envisions the development of ultra-low specific weight yet high-strength composite honeycomb materials, aimed at enhancing the performance of aerospace and defense platforms by reducing weight without compromising structural integrity. In the medium term, the path emphasizes the widespread adoption of environmentally friendly design principles, including the use of sustainable and recyclable materials in honeycomb configurations. Finally, in the long term, the scenario projects the reduction of production costs and the establishment of new industrial standards through the mainstream adoption of sustainable honeycomb structures, positioning them as a core component of next-generation defense and aerospace systems.

In addition to the prioritized scenario, the futures wheel revealed several alternative futures specifically related to honeycomb material technologies. Some scenario paths focused on the development of self-healing honeycomb structures, aimed at enhancing the structural resilience of aerospace and defense platforms and enabling multifunctionality, such as integrated thermal conductivity and real-time sensing capabilities. Other futures emphasized advancements in the manufacturing of honeycomb materials, including the use of additive manufacturing techniques and innovative bonding methods designed to improve production flexibility, reduce costs, and eliminate the need for traditional adhesives honeycomb sandwich structures. A separate group of scenarios highlighted the integration of biobased and recyclable materials into honeycomb structures.

To answer the second research question “What policies are needed to enable the realization of this prioritized future?” a second focus group was conducted using the Backcasting method. Participants worked backward from the prioritized scenario to identify enabling actions and systemic interventions. This session provided valuable

insights beyond technical materials development, revealing critical challenges in academia–industry collaboration, gaps in indigenous R&D and manufacturing capabilities, and the need for sustainability-oriented innovation. Overall, the combined use of exploratory and normative foresight methods allowed for both the identification of a strategic technological trajectory and the formulation of actionable policy directions tailored to the defense and aerospace context.

To answer the second research question "What policies are needed to enable the realization of this prioritized future?" a second focus group was conducted using the Backcasting method. This normative foresight tool enabled participants to assume that the prioritized future scenario had already been successfully realized and to work backward to identify the key factors, actors and actions that would have made such a future possible. The prioritized future in question envisions a progression from the development of ultra-lightweight, high-strength composite honeycomb materials to the widespread adoption of environmentally friendly designs, and ultimately to cost reduction and the establishment of new industrial standards through the integration of sustainable honeycomb structures.

Grounded in this imagined future state, participants collaboratively mapped out the enabling conditions, decision points, and coordinated actions needed across short-, medium-, and long-term time frames. The session was conducted online and facilitated through a digital whiteboard platform, allowing for interactive engagement and real-time scenario construction. Participants considered the roles of key actors within the Triple Helix model, government, industry, and academia, and reflected on both enablers and systemic barriers. This process not only generated future-oriented policy recommendations but also revealed persistent systemic challenges. These included uncoordinated research initiatives, insufficient prototyping infrastructure, and limited diffusion of sustainability-oriented materials development. A particularly critical gap identified during the session was the absence of indigenous capability in the development and production of honeycomb material structures especially those based on advanced composite technologies. As a result, the Backcasting session produced a series of policy-relevant insights and actionable suggestions, which are presented in detail in the following section.

5.2. Policy Recommendations

The policy recommendations presented in this section extend beyond supporting the transition from the development of ultra-lightweight, high-strength composite honeycomb materials to the widespread adoption of environmentally friendly designs. In addition, they respond broader structural deficiencies revealed during the foresight process particularly the complete absence of indigenous producers specializing in composite honeycomb structures and Türkiye's dependence on foreign suppliers in this materials technology area. This urgent national need forms the basis for the proposed actions outlined in Table 12, which covers short-term policy recommendations.

The research outcomes indicate that building national capability in composite honeycomb technologies should begin with a structured initiative to identify Türkiye's specific performance and application requirements for aerospace-grade honeycomb materials, as outlined in Policy 2 of Table 12. In tandem, Policy 1 advocates publicly funded R&D programs for universities and research laboratories to support the development of thermoplastic-based honeycomb structures compatible with modern composite systems. Since no domestic manufacturer currently exists, Policy 4 in the same table calls for direct public support to establish indigenous production capabilities from the ground up. These efforts would be complemented by the exploration of advanced geometry and topology variations in honeycomb design, promoted under Policy 3, to increase design flexibility and adaptability for various aerospace applications.

Moving into the medium term, the emphasis shifts to bridging the research-to-industry gap and consolidating infrastructure, as detailed in Table 13. Policy 7 recommends transitioning university-developed thermoplastic honeycomb materials into industrial prototypes through structured validation programs, while Policy 5 focuses on the creation of domestic simulation tools to assess performance prior to production. Enhancing sustainability is another key priority according to the prioritized future. In this context Policy 6 proposes applied research on recycling and robotic manufacturing technologies to increase the efficiency and eco-compatibility of thermoplastic

honeycombs. To ensure that public R&D investments yield practical returns, Policy 8 calls for the enforcement of mechanisms that mandate the use of domestic innovations in defense procurement and related industrial applications.

Institutional coordination is addressed through Policy 9, which recommends the creation of national centers of excellence in honeycomb technologies to unify the efforts of government, academia, and industry. These centers would be instrumental in implementing other key policies such as Policy 10, which outlines the need for a national database and material catalog to enhance industrial usage and export potential. Moreover, Policy 11 proposes benchmarking and standardization frameworks to facilitate verification and open data access, helping to systematize development efforts across the sector.

Looking ahead to the long term, the focus shifts toward sustaining technological development while enhancing the functional capabilities of lightweight and high-strength honeycomb materials, as described in Table 14.Policy 12 supports the development of adaptive 3D lattice structures tailored to specific load conditions, while Policy 13 addresses the need for certification procedures to validate long-term performance. A long-term policy focus is placed on expanding the functional scope of honeycomb materials, Policy 14 encourages the development of honeycomb materials with integrated sound isolation properties. In terms of sustainability, Policy 15 recommends embedding lifecycle and environmental impact metrics into the design, testing, and certification of defense-related materials. Finally, Policy 16 calls for the establishment of a centralized digital infrastructure, supported by national centers of excellence, to enable efficient simulation, data sharing, and certification processes in honeycomb materials technologies.

Taken together, these policy recommendations offer a coordinated strategy that aligns with the prioritized future scenario identified in this thesis. They are intended to support the development of national capabilities in composite honeycomb technologies and contribute to reducing Türkiye’s dependency in this strategically important area of aerospace and defense materials.

In this context, following the completion of my study, I proposed a set of targeted policy actions to the relevant units within a leading aerospace and defense firm. These actions were designed to serve two distinct but complementary purposes: to inform the company's long-term technology roadmap and to support the planning of future university–industry collaboration efforts. The technology roadmap, conceptualized as a structured planning tool, connects the firm's evolving technological capabilities with its strategic goals, while also responding to dynamic external conditions (Phaal et al., 2004). Within this framework, the roadmap recognizes the firm's advanced in-house technological infrastructure as a strategic asset. At the same time, it provides a structured basis for initiating external collaborations when necessary either through formal partnerships or targeted project engagements.

Within the technology roadmap proposals, developing thermoplastic honeycomb materials compatible with composite systems which is aligned with Policy 1 was positioned as an early-stage opportunity. This topic could be initiated through the firm's own infrastructure and testing capabilities. Likewise, Policy 7 was also mapped onto the emphasizing the industrial transition of university-developed thermoplastic honeycomb prototypes through structured validation programs. This topic was framed could be academically initiated but piloted and adapted within the company's advanced R&D environment.

In parallel, several topics were identified as more suitable for collaborative research projects between the firm and external academic or research institutions. These include the integration of sound-isolation features into honeycomb structures (Policy 14), the geometric and topological diversification of honeycomb design (Policy 3), and efforts to improve recyclability and introduce robotic manufacturing processes (Policy 6). These areas represent long-term innovation potentials that would benefit from academic leadership, while leveraging the firm's experimental infrastructure for validation and application.

Together, these proposals were submitted to the company for internal evaluation and constitute a concrete outcome of this research.

Table 12. Policy Proposals for the Short Term (0–5 Years) in Türkiye

No	Policy	Problem	Method (How)	Policy Instrument	Potential Responsible Actor	Metric	Time Frame
1	Public R&D support should be directed toward the development of thermoplastic (TP) honeycomb materials compatible with composite systems.	Incompatibility of existing honeycomb structures (e.g., Nomex) with TP composites; lack of TP-based honeycomb in the market	Selection of compatible TP resin system, cell geometry design and optimization, prototyping, structural tests	Publicly funded R&D projects within priority research areas	Universities, research laboratories (early stage)	TP honeycomb materials demonstrating mechanical and environmental performance at least equivalent to Nomex® under same gsm and geometry	Short term
2	Defense industry stakeholders should coordinate the systematic identification of application-specific requirements for aerospace honeycomb materials.	Highly specific material requirements in aerospace and defense fields; unclear or undocumented needs	Conducting application-specific needs analyses, identifying structural and environmental requirements for flight platforms	Demand and need based R&D steering mechanisms	Defense industry firms	Number of identified usage scenarios; published requirement documents	Short term
3	Public research initiatives should focus on the geometric and topological diversification of honeycomb structures to enhance their adaptability across different platforms.	Limited design flexibility of classic honeycomb structures; lack of adaptability to various applications	Hybrid design trials varying geometry, cell orientation, stacking, and density gradients; screening tests to determine optimal structures	Publicly funded R&D projects within priority research areas	Universities, research laboratories	Number of layout variants developed; prototype variations tested; number of published patents/articles	Short term
4	Public support should be provided to encourage the establishment of indegenous manufacturers of aerospace-grade honeycomb materials.	Lack of domestic firms with production experience in aerospace-grade honeycomb materials	Identifying needs and technical specifications of firms currently importing honeycombs; defining lightweight and durable honeycomb targets	Sectoral needs analysis and incentive support programs	Ministry of Industry and Technology, TÜBİTAK, Defense Industry Agency (SSB)	Increase in number of domestic producers; decrease in foreign dependency	Short term

Source: Author

Table 13. Policy Proposals for the Medium Term (5-10 Years) in Türkiye

No	Policy	Problem	Method (How)	Policy Instrument	Potential Responsible Actor	Metric	Time Frame
5	Public funding should be allocated to develop simulation tools tailored to the structural and functional needs of aerospace and defense applications.	Lack of simulation prior to production to assess usability	Designing domestic software and simulation programs	R&D support programs, software incentives	Universities, research labs, TÜBİTAK	Number of simulation tools developed; adoption rate by industry	Medium term
6	Applied research programs should be initiated to improve the recyclability of thermoplastic honeycomb materials and develop robotic production technologies.	Limited sustainability and efficiency of TP-based honeycombs	Applied research in materials science and robotics	Public R&D funds, TÜBİTAK programs, university-industry collaborations	Universities, research centers, tech transfer offices	Increase in recyclable composites rate; number of prototypes; academic publications	Medium term
7	University-developed thermoplastic honeycomb materials should be transitioned into industry through structured prototyping and field validation programs.	Lack of integration of academic materials into industry; prototyping gap	Tech transfer protocols, material validation, prototyping, field testing	Tech transfer support (TÜBİTAK 1505, KOSGEB), clustering incentives	Industrial firms, TTOs, university R&D centers	Successful field-tested industrial prototype; reaching TRL ≥ 6	Medium term
8	Enforcement mechanisms should be implemented to ensure that publicly funded R&D outputs are integrated into national defense and industrial platforms.	Public R&D results not implemented; domestic capabilities neglected	Implementation tracking systems, institutional accountability and sanction mechanisms	Regulatory adjustments with mandatory application; performance evaluation system	Public defense procurement and oversight institutions	Ratio of commercialized/implemented national R&D outputs; local content in public projects	Medium term

Source: Author

Table 13. (continued)

9	Centers of excellence dedicated to honeycomb materials should be established to foster cross-sectoral collaboration and shared R&D infrastructure.	Weak collaboration between academia and industry; insufficient shared infrastructure	Establishment of joint R&D platforms and multi-stakeholder governance structures	Government-funded R&D center programs, cooperation protocols	SSB, TÜBİTAK, universities, defense companies	Number of centers founded; workshops/presentations held; joint publications/patents	Medium term
10	A national database and catalog system should be developed to document and classify domestically produced honeycomb materials for industrial usage and export.	Lack of detailed technical catalogs; export potential not realized due to data gap	Data collection and classification in cooperation with test labs	R&D support; infrastructure investment for data systems	SSB, TÜBİTAK, MoD	Number of catalogs; export performance; industrial usage of catalog data	Medium term
11	Benchmarking and standardization protocols should be created for honeycomb and lattice structures, supported by open data and shared verification systems.	No standard test & data sharing infrastructure; fragmented and closed data environment	Open data infrastructure, shared verification systems, benchmarking lattice with honeycomb	Development of certification processes, open platforms, performance-based evaluations	TSE, regulators, industry consortia, R&D institutions	Validated certification protocols; public lattice-honeycomb comparison datasets	Medium term

Table 14. Policy Proposals for the Long Term (10+ Years) in Türkiye

No	Policy	Problem	Method (How)	Policy Instrument	Potential Responsible Actor	Metric	Time Frame
12	Public R&D programs should support the design of advanced 3D lattice structures that are adaptable to platform-specific load conditions.	Lack of performance under variable loads; need for platform-specific optimization	Advanced computational material design, simulation, testing, prototyping	Public R&D funding (e.g., TÜBİTAK), university-industry consortia	Universities (esp. engineering faculties), research institutes, defense industry	TRL level of developed lattices; strength-to-weight ratios; test results	Long term
13	Nationally validated verification procedures should be developed to certify the long-term performance and reliability of honeycomb materials.	Need for long-term impact and reliability assurance	Sector-validated verification systems covering mechanical, environmental, and operational tests	New national test standards, regulatory frameworks, technical guidelines	Ministry of Industry, SSB, TÜBİTAK, test labs	Number of verification protocols developed; industry adoption rate; global recognition	Long term
14	Sound-isolating honeycomb materials should be developed through the integration of acoustic properties into structural material design.	Lack of multifunctionality; current structures optimized for compressive load only	Integration of acoustics and material science; multifunctional design principles	Collaborative R&D funds, TÜBİTAK support, defense innovation grants	Universities, research centers, defense companies	Acoustic isolation ratings; number of functions; IP count	Long term
15	Sustainability standards should be systematically incorporated into the development and certification processes of honeycomb materials in the defense sector.	Lack of systemic sustainability approach in defense industry	Lifecycle analysis integration into design and production; environmental KPIs	National sustainability strategies, environmental regulations, green compliance schemes	SSB, Ministry of Environment, Ministry of Industry	Compliance rate with net-zero goals; environmental impact reports; green-certified companies	Long term
16	A centralized digital infrastructure should be created for managing certification and simulation data within national excellence centers.	Uncoordinated simulation/certification systems; lack of unified infrastructure	Centralized data collection; common standards and digital sharing infrastructure	Creation of a National Defense Materials Database; joint certification schemes	SSB, TSE, TÜBİTAK, MoD, universities, defense firms	Number of databases; standardized honeycomb types; usage in defense projects	Long term

5.3. Limitations And Suggestions For Future Research

This thesis presents a structured foresight methodology centered on honeycomb material technologies, emphasizing their strategic role in the defense and aerospace sectors as a representative case of advanced materials technologies. While the framework provides a novel combination of participatory scenario development and prioritization, certain limitations must be acknowledged to better contextualize the results and guide their interpretation.

A primary methodological limitation of the study stems from the treatment of scenario paths within the prioritization framework. Although the foresight process successfully generated multiple scenario paths each structured across short-, medium-, and long-term horizons and internally coherent the analysis focused on only one prioritized pathway for the application of the Backcasting method. I made this decision primarily to ensure the manageability of the thesis and to allow for in-depth qualitative exploration within a limited scope. However, this focus necessarily limited the investigation of other scenario paths, which may reflect equally plausible but strategically distinct futures. In rapidly evolving technological domains such as materials technologies, excluding these alternatives risks overlooking critical developments or divergent strategic trajectories. In addition, the study adopted a strict inclusion criterion that required scenario chains to include all three-time horizons (short-, medium-, and long-term) to be considered for prioritization and further analysis. While this rule supported structural consistency, it led to the systematic exclusion of foresight statements that existed only in the short or medium term. Such partial but potentially meaningful futures may have captured incremental innovations, weak signals, or disruptive developments that do not yet form a complete scenario chain but are still of strategic relevance. Together, the narrowing of focus to a single pathway and the exclusion of non-complete scenarios reduced the breadth of futures explored. While these methodological choices were justified by the need for analytical depth and feasibility within the thesis framework, they also represent a limitation in terms of scenario inclusivity and comprehensiveness.

Another significant constraint encountered during the study was related to the composition of focus group participants. Although at least one participant represented

each actor of the Triple Helix model ,government, industry, and academia, the overall composition leaned heavily toward industry professionals. This imbalance, despite deliberate design choices to ensure diversity, may have led to foresight outcomes that reflect more practice-oriented and engineering-focused viewpoints. To mitigate the effect of this imbalance, the sessions were conducted with a structured facilitation approach aimed at ensuring equal participation, balancing dominant voices, and encouraging contributions from underrepresented perspectives. Nevertheless, the underrepresentation of policy and academic voices may have limited the depth of long-term strategic thinking in the discussions, leaving certain broader implications underexplored.

Another notable limitation relates to the use of patent analysis as a key validation step in the early phase of the study. Although patent data offer a structured and empirical way to trace technological relevance, they tend to miss innovations that have not yet entered the patenting process—particularly early-stage research, informal knowledge, or experimental developments. This gap is especially relevant in fast-moving and interdisciplinary fields like advanced materials, where valuable insights and breakthroughs may not be formally documented or may emerge outside traditional intellectual property systems.

Despite these limitations, the thesis establishes a strong foundation for future research by integrating foresight and prioritization methodologies in a novel and complementary manner. Its methodological design offers significant value not only to scholars working in Multi-Criteria Decision Making (MCDM) but also to researchers in futures studies and foresight. By bridging scenario-based thinking with structured evaluation techniques, the study provides a robust framework that can inform both theoretical inquiry and applied foresight practices. Building on this foundation, I identified several directions for further research.

One immediate opportunity for future studies lies in expanding the scope of analysis to include not only the single prioritized scenario pathway but also the additional scenario chains that were generated during the Futures Wheel process but ultimately excluded from the Backcasting phase. These alternative paths, while not ranked

highest in the initial evaluation may still embody distinct possibilities or reflect critical dimensions of future technological developments that were underrepresented in the dominant narrative. By revisiting and systematically analyzing these secondary or lower-priority scenarios, researchers could uncover disruptive possibilities or sector-specific concerns that were overshadowed by the most consensus-driven future. This expanded lens would contribute to a more pluralistic understanding of how honeycomb materials and by extension, other advanced materials technologies might influence the future of defense and aerospace in diverse ways.

Moreover, future research could also benefit from developing an enhanced prioritization model that allows for the inclusion of incomplete scenario chains that contain only short- or medium-term nodes and lack a full temporal progression across the long-term horizon. While these partial scenarios were excluded in the current study to maintain methodological coherence, they may still offer important insights into incremental developments, near-future inflection points, or transitional innovations that play a decisive role in shaping long-term strategic trajectories. A revised framework that accommodates these incomplete but thematically significant foresight statements would allow for a more nuanced mapping of possible futures. Such a methodological evolution would not only improve the inclusiveness of the analysis but also help capture a wider array of technological signals and policy challenges.

Furthermore, the study's prioritization process, which combined Analytic Hierarchy Process (AHP) with temporal weighting, proved robust overall, yet demonstrated limitations that suggest the need for methodological enhancements. In cases where multiple paths received identical final scores, the need for complementary evaluation tools became evident. In cases where multiple paths received identical final scores, the need for complementary evaluation tools became evident. Future research might explore hybrid or dynamic weighting models for example, those that factor in scenario complexity or uncertainty levels to provide finer differentiation between close-ranking scenarios.

Another future research direction for advancement involves integrating advanced computational methods such as fuzzy logic, machine learning, or Bayesian inference into the foresight process. These tools can help manage ambiguity, model scenario

evolution over time, and introduce real-time adaptability into prioritization algorithms. Such capabilities are particularly relevant for high-stakes, high-uncertainty sectors like defense and aerospace, where rapid technological change is the norm. In addition, future studies could experiment with replacing or complementing human expert groups with artificial intelligence systems, posing the same foresight questions to different AI models (e.g., comparing the outputs of DeepSeek AI and OpenAI). Such comparative exercises would not only test the methodological robustness of the suggested foresight framework when applied through AI but also provide insights into how AI perspectives converge with or diverge from domain experts, as well as how the perspectives of different AI tools themselves may change across models or over time.

Also worth investigating is how participant profiles such as professional background or institutional affiliation influence the type and orientation of foresight outputs. Observations from this study suggest that the technical depth and strategic scope of foresight statements often reflect participants' roles in the future view. Systematically analyzing these differences could help refine facilitation strategies, increase methodological transparency, and allow for more targeted synthesis of stakeholder insights.

Finally, comparative studies across national or sectoral contexts could test the adaptability of this foresight methodology. Applying it within different innovation ecosystems for example, in countries with varying levels of defense R&D capacity or different cultural approaches to long-term planning would offer insights into the universal and context-specific elements of technology foresight. Moreover, embedding foresight exercises directly into live policy or R&D programs could enable feedback mechanisms, allowing the ongoing evaluation of whether prioritized scenarios are materializing as expected, and whether policy measures are having the intended effects.

In sum, while this thesis offers a focused case study on honeycomb materials in the defense and aerospace sectors, its broader value lies in the novel methodological framework it introduces combining Futures Wheel with a structured prioritization

model supported by an interactive digital tool. The integration of foresight and decision-making tools provides a foundation not only for academic researchers in Multi-Criteria Decision Making (MCDM) and futures studies, but also for institutions aiming to adopt future-oriented planning practices. By demonstrating how scenarios can be prioritized and translating foresight statements into concrete and actionable policy suggestions, this thesis contributes to the development of more resilient, adaptive, and informed policy-making structures. Its methodology is adaptable across technological domains and scalable through digital platforms, making it a practical framework for both scholarly research and institutional foresight effort.

REFERENCES

Acanfora, V., Sellitto, A., Russo, A., Zarrelli, M., & Riccio, A. (2023). Experimental investigation on 3D printed lightweight sandwich structures for energy absorption aerospace applications. *Aerospace Science and Technology*, *137*, 108276. https://doi.org/10.1016/j.ast.2023.108276

Al-Mamun, A.-M., Hossain, M. R., Iqbal, M. A., Haque, M. Z., & Sharmin, M. M. (2024). Recent developments in the synthesis of composite materials for aerospace: Case study. *Material Science & Engineering International Journal*, *8*(3), 109–116. https://doi.org/10.15406/mseij.2024.08.00243

Altuntaş, S., & Dereli, T. (2016). Savunma Sanayiinde Teknoloji Gelişimi: Mühimmat ve Tahrip Teknolojileri Üzerine Bir Uygulama. *Journal of Entrepreneurship and Innovation Management*, *5*(2), 105–123.

Ambekar, R. S., Kushwaha, B., Sharma, P., Bosia, F., Fraldi, M., Pugno, N. M., & Tiwary, C. S. (2021). Topologically engineered 3D printed architectures with superior mechanical strength. *Materials Today*, *48*, 72–94. https://doi.org/10.1016/j.mattod.2021.03.014

Aminanda, Y., Castanié, B., Barrau, J.-J., & Thevenet, P. (2005). Experimental Analysis and Modeling of the Crushing of Honeycomb Cores. *Applied Composite Materials*, *12*(3–4), 213–227. https://doi.org/10.1007/s10443-005-1125-3

Another Way Consulting (Producer). (2015, April 2). *What is the Implications Wheel* [Video recording]. https://www.youtube.com/watch?v=pCuyinozXZU

Apelian, D. (2007). Looking beyond the last 50 years: The future of materials science and engineering. *JOM*, *59*(2), 65–73. https://doi.org/10.1007/s11837-007-0024-5

Armanto, A. R. A. (2024). Futures participation as anticipatory practice—What do futures workshops do? *European Journal of Futures Research*, *12*(1), 3. https://doi.org/10.1186/s40309-024-00226-4

Ashby, M., & Johnson, K. (2003). The art of materials selection. *Materials Today*, *6*(12), 24–35. https://doi.org/10.1016/S1369-7021(03)01223-9

Babus, S. W., Carlson, T. A., Jones, W. F., Boslego, D. V., Davis, M. K., Dion, D., Doryland, D. J., Harris, M. W., Hemmrich, S. B., & Hollman, K. A. (2004). *Spring 2004 Industry Study Final Report: Strategic Materials* (20319–5062). The Industrial College of the Armed Forces, National Defense University.

Belton, V., & Stewart, T. J. (2002). *Multiple Criteria Decision Analysis*. Springer US. https://doi.org/10.1007/978-1-4615-1495-4

Benedetti, M., Du Plessis, A., Ritchie, R. O., Dallago, M., Razavi, N., & Berto, F. (2021). Architected cellular materials: A review on their mechanical properties towards fatigue-tolerant design and fabrication. *Materials Science and Engineering: R: Reports*, *144*, 100606. https://doi.org/10.1016/j.mser.2021.100606

Bengston, D. N. (2016). The Futures Wheel: A Method for Exploring the Implications of Social–Ecological Change. *Society & Natural Resources*, *29*(3), 374–379. https://doi.org/10.1080/08941920.2015.1054980

Bengston, D. N., Westphal, L. M., & Dockry, M. J. (2020). Back from the future: The backcasting wheel for mapping a pathway to a preferred future. *World Futures Review*, *12*(3), 270–278. https://doi.org/10.1177/1946756720929724

Bibri, S. E., & Krogstie, J. (2019). Generating a vision for smart sustainable cities of the future: A scholarly backcasting approach. *European Journal of Futures Research*, *7*(1), 5. https://doi.org/10.1186/s40309-019-0157-0

Bilge, B. (2018). *Imagery intelligence technology foresight and modeling of mobile application in the defense industry* [Master's thesis, Middle East Technical University, Middle East Technical University]. https://open.metu.edu.tr/handle/11511/27890

Birman, V., & Kardomateas, G. A. (2018). Review of current trends in research and applications of sandwich structures. *Composites Part B: Engineering*, *142*, 221–240. https://doi.org/10.1016/j.compositesb.2018.01.027

Bitzer, T. (1997). *Honeycomb Technology*. Springer Netherlands. https://doi.org/10.1007/978-94-011-5856-5

Bloor, M., Frankland, J., Thomas, M., & Robson, K. (2001). *Focus Groups in Social Research*. SAGE Publications Ltd. https://doi.org/10.4135/9781849209175

Bóck, C., & Kettemann, M. C. (2024). *Mapping the Future of Technological Innovations* [Foresight Paper No. 3]. REGROUP Project. https://osf.io/6u37k

Bradfield, R., Wright, G., Burt, G., Cairns, G., & Van Der Heijden, K. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures*, *37*(8), 795–812. https://doi.org/10.1016/j.futures.2005.01.003

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Bruneel, J., D'Este, P., & Salter, A. (2010). Investigating the factors that diminish the barriers to university–industry collaboration. *Research Policy*, *39*(7), 858–868. https://doi.org/10.1016/j.respol.2010.03.006

Burnett, M., Ashton, P., Hunt, A., Kamenetsky, D., McGinty, N., Quinn, D., Ryan, S., Shekhter, A., & Solomon, P. (2018). *Advanced Materials and Manufacturing – Implications for Defence to 2040* (DST-Group-GD-1022). Defence Science and Technology Group.

Burte, H. M. (1995). Emerging Materials Technology. In D. O. Thompson & D. E. Chimenti (Eds.), *Review of Progress in Quantitative Nondestructive Evaluation* (Vol. 14, pp. 1–22). Springer US. https://doi.org/10.1007/978-1-4615-1987-4_1

Callister, W. D., & Rethwisch, D. G. (2020). *Materials Science and Engineering: An Introduction* (10th ed.). John Wiley & Sons.

Candy, S., & Dunagan, J. (2017). Designing an experiential scenario: The People Who Vanished. *Futures*, *86*, 136–153. https://doi.org/10.1016/j.futures.2016.05.006

Cann, A. (2010). *Scenario-Based Strategic Planning in the U.S. Army Corps of Engineers Civil Works Program*. U.S. Army Corps of Engineers.

Castanie, B., Bouvet, C., & Ginot, M. (2020). Review of composite sandwich structure in aeronautic applications. *Composites Part C: Open Access*, *1*, 100004. https://doi.org/10.1016/j.jcomc.2020.100004

Çepni, E. (2019). Who should govern on what principles? The future of decision making combining nudge with scenarios to reach eutopia. *Cadmus*, *3*(6), 163–177.

Chang, P.-L., Wu, C.-C., & Leu, H.-J. (2010). Using patent analyses to monitor the technological trends in an emerging field of technology: A case of carbon nanotube field emission display. *Scientometrics*, *82*(1), 5–19. https://doi.org/10.1007/s11192-009-0033-y

Charnes, A., & Cooper, W. W. (1957). *Management Models and Industrial Applications of Linear Programming*. *4*(1), 38–91.

Charnes, A., Cooper, W. W., & Ferguson, R. O. (1955). Optimal Estimation of Executive Compensation by Linear Programming. *Management Science*, *1*(2), 138–151. https://doi.org/10.1287/mnsc.1.2.138

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). *A Data Envelopment Analysis Approach to Evaluation of the Program Follow Through Experiment in U.S. Public School Education*. The University of Texas.

Çifçi, H. (2019). *Technology Foresight and Modeling: Turkish Cybersecurity Foresight 2040* [Doctoral dissertation, Middle East Technical University, Middle East Technical University]. https://open.metu.edu.tr/handle/11511/43371

Comet, M., Martin, C., Schnell, F., & Spitzer, D. (2019). Energetic Nanoparticles and Nanomaterials for Future Defense Applications. *Human Factors and Mechanical Engineering for Defense and Safety*, *3*(1), 1. https://doi.org/10.1007/s41314-019-0016-6

Corbin, J., & Strauss, A. (1996). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (4th ed.). SAGE Publications.

Creswell, J. W. (2022). *A Concise Introduction to Mixed Methods Research* (2nd ed.). SAGE Publications.

Daim, T. U., Rueda, G., Martin, H., & Gerdsri, P. (2006). Forecasting emerging technologies: Use of bibliometrics and patent analysis. *Technological Forecasting and Social Change*, *73*(8), 981–1012. https://doi.org/10.1016/j.techfore.2006.04.004

Dong, Y., Zhang, G., Hong, W.-C., & Xu, Y. (2010). Consensus models for AHP group decision making under row geometric mean prioritization method. *Decision Support Systems*, *49*(3), 281–289. https://doi.org/10.1016/j.dss.2010.03.003

Dreborg, K. H. (1996). Essence of backcasting. *Futures*, *28*(9), 813–828. https://doi.org/10.1016/S0016-3287(96)00044-4

Dreyer, I., & Stang, G. (2013). *Foresight in governments – practices and trends around the world*.

Edwards, W. (1971). *The engineering economic summer symposium series*. *6*, 119–129.

Epp, F. A., Moesgen, T., Salovaara, A., Pouta, E., & Gaziulusoy, İ. (2022). Reinventing the wheel: The future ripples method for activating anticipatory capacities in innovation teams. *Designing Interactive Systems Conference*, 387–399. https://doi.org/10.1145/3532106.3534570

European Commission. Joint Research Centre. (2023). *Identifying future critical technologies for space, defence and related civil industries: A technology foresight exercise to support further EU policy developments.* Publications Office. https://data.europa.eu/doi/10.2760/005929

Farber, D., & Lakhtakia, A. (2009). Scenario planning and nanotechnological futures. *European Journal of Physics*, *30*(4), S3–S15. https://doi.org/10.1088/0143-0807/30/4/S02

Farcal, L., Pineiro, A. M., Sintes, J. R., Rauscher, H., & Rasmussen, K. (2023). Advanced materials foresight: Research and innovation. *F1000Research*, *11*(1532). https://f1000research.com/articles/11-1532/v2

Farinha, J., Vesnic-Alujevic, L., & Hristova, M. (2023). *Identifying future critical technologies for space, defence and related civil industries* (JRC134926). European Commission, Joint Research Centre. https://data.europa.eu/doi/10.2760/005929

Farooq, U., Ahmad, M. S., Rakha, S. A., Ali, N., Khurram, A. A., & Subhani, T. (2017). Interfacial Mechanical Performance of Composite Honeycomb Sandwich Panels for Aerospace Applications. *Arabian Journal for Science and Engineering*, *42*(5), 1775–1782. https://doi.org/10.1007/s13369-016-2307-z

Farrington, T., Crews, C., & Blenkle, J. (2013). Implications Wheels: Structured Brainstorming about the Future. *Research-Technology Management*, *56*(3), 56–58. https://doi.org/10.5437/08956308X5603008

Figueira, J., Greco, S., & Ehrogott, M. (2005). *Multiple Criteria Decision Analysis: State of the Art Surveys* (Vol. 78). Springer New York. https://doi.org/10.1007/b100605

Finlay, L. (2002). Negotiating the swamp: The opportunity and challenge of reflexivity in research practice. *Qualitative Research*, *2*(2), 209–230. https://doi.org/10.1177/146879410200200205

Fleck, N. A., Deshpande, V. S., & Ashby, M. F. (2010). Micro-architectured materials: Past, present and future. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *466*(2121), 2495–2516. https://doi.org/10.1098/rspa.2010.0215

Gentner, D., Stelzer, B., Ramosaj, B., & Brecht, L. (2018). Strategic Foresight of Future B2B Customer Opportunities through Machine Learning. *Technology Innovation Management Review*, *8*(10), 5–17. https://doi.org/10.22215/timreview/1189

Glenn, J. C. (2009). The Futures Wheel. In *Futures Research Methodology* (Version 3). The Millennium Project.

Government Office for Science (UK). (2024). *The Futures Toolkit* [Toolkit]. Government Office for Science.

Grunwald, A. (2009). Technology Assessment: Concepts and Methods. In *Philosophy of Technology and Engineering Sciences* (pp. 1103–1146). Elsevier. https://doi.org/10.1016/B978-0-444-51667-1.50044-6

Guo, H., Zhang, Q., Liu, Y., & Zhao, D. (2023). Properties and Defence Applications of Carbon Nanotubes. *Journal of Physics: Conference Series*, *2478*(4), 042010. https://doi.org/10.1088/1742-6596/2478/4/042010

Hales, T. C. (2001). The Honeycomb Conjecture. *Discrete & Computational Geometry*, *25*(1), 1–22. https://doi.org/10.1007/s004540010071

Hamel, S., Ims, R., & Yoccoz, N. (2021). Challenges and opportunities when implementing strategic foresight: Lessons learned when engaging stakeholders in climate-ecological research. *Climate Research*, *86*, 29–35. https://doi.org/10.3354/cr01653

Hannemann, B. (2018). *Multifunctional metal-carbon-fibre composites for damage tolerant and electrically conductive lightweight structures* (IVW-Schriftenreihe, Band 128). Institut für Verbundwerkstoffe GmbH.

Hendrix, T., & Nasution, S. Y. (2023). The learning process on utilization foresight technology of patent information: Sorghum plant from bioethanol. *Knowledge Management & E-Learning: An International Journal*, *15*(4), 703–721. https://doi.org/10.34105/j.kmel.2023.15.038

Hines, A. (2008). Thinking about the Future: Guidelines for Strategic Foresight. *Foresight*, *10*(1), 79–80. https://doi.org/10.1108/14636680810856044

Hsieh, C.-H. (2013). Patent value assessment and commercialization strategy. *Technological Forecasting and Social Change*, *80*(2), 307–319. https://doi.org/10.1016/j.techfore.2012.09.014

Hu, J. (2024). Nanomaterials in aerospace: Revolutionizing flight and exploration through nanoscale advancements. *Applied and Computational Engineering*, *60*(1), 1–5. https://doi.org/10.54254/2755-2721/60/20240821

Hussain, M., Tapinos, E., & Knight, L. (2017). Scenario-driven roadmapping for technology foresight. *Technological Forecasting and Social Change*, *124*, 160–177. https://doi.org/10.1016/j.techfore.2017.05.005

Industrial Research Institute, Inc. (2014). *IRI2038 Futures Study*. Industrial Research Institute, Inc. https://iriweb.org/resources/march-3-2017-foresight-and-the-future-of-rd/

Ishizaka, A., & Nemery, P. (2013). *Multi-criteria decision analysis: Methods and software*. Wiley. https://doi.org/10.1002/9781118644898

Jaafar, M., Nouari, M., Makich, H., & Moufki, A. (2021). 3D numerical modeling and experimental validation of machining Nomex® honeycomb materials. *The International Journal of Advanced Manufacturing Technology*, *115*(9–10), 2853–2872. https://doi.org/10.1007/s00170-021-07336-4

Joint Research Centre. Institute for Environment and Sustainability. (2008). *Backcasting approach for sustainable mobility*. European Commission. Publications Office. https://data.europa.eu/doi/10.2788/77831

Kamal, I. (2018). Prospects of Some Applications of Engineered Nanomaterials: A review. *Open Access Journal of Biomedical Engineering and Biosciences*, *2*(5). https://doi.org/10.32474/OAJBEB.2018.02.000149

Kamble, Z. (2023). Advanced structural and multi-functional sandwich composites with prismatic and foam cores: A review. *Wiley*, 16355–16382. https://doi.org/10.1002/pc.27849

Katoch, R. (2006). Defence Economics: Core Issues. *Strategic Analysis*, *30*(2), 279–309. https://doi.org/10.1080/17540054.2006.12288833

Kesarwani, S. (2017). Polymer Composites in Aviation Sector. *International Journal of Engineering Research And*, *V6*(06), IJERTV6IS060291. https://doi.org/10.17577/IJERTV6IS060291

Kiger, M. E., & Varpio, L. (2020). Thematic analysis of qualitative data: AMEE Guide No. 131. *Medical Teacher*, *42*(8), 846–854. https://doi.org/10.1080/0142159X.2020.1755030

Kladovasilakis, N., Tsongas, K., Karalekas, D., & Tzetzis, D. (2022). Architected Materials for Additive Manufacturing: A Comprehensive Review. *Materials*, *15*(17), 5919. https://doi.org/10.3390/ma15175919

Klein, G. (2008). Performing a Project Premortem. *IEEE Engineering Management Review*, *36*(2), 103–104. https://doi.org/10.1109/EMR.2008.4534313

Kok, K., Van Vliet, M., Bärlund, I., Dubel, A., & Sendzimir, J. (2011). Combining participative backcasting and exploratory scenario development: Experiences from the SCENES project. *Technological Forecasting and Social Change*, *78*(5), 835–851. https://doi.org/10.1016/j.techfore.2011.01.004

Köksalan, M. M., Wallenius, J., & Zionts, S. (2011). *Multiple criteria decision making: From early history to the 21st century*. World Scientific.

Kvasha, T. & L. Musina. (2021). Foresight as a tool of public administration in the field of science, technology and innovation. *Economics, Entrepreneurship, Management*, *8*(1), 90–97. https://doi.org/10.23939/eem2021.01.090

Linturi, R., Höyssä, M., Kuusi, O., & Vähämäki, V. (2022). Radical Technology Inquirer: A methodology for holistic, transparent and participatory technology foresight. *European Journal of Futures Research*, *10*(1), 18. https://doi.org/10.1186/s40309-022-00206-6

Liu, X., Furrer, D., Kosters, J., & Holmes, J. (2018). *Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems*.

Lombardo, D., & Wang, K. (2021). *Advances in Materials Science and Engineering* (1st ed.). CRC Press. https://doi.org/10.1201/9781003225850

Ma, Q., Rejab, M., Siregar, J., & Guan, Z. (2021). A review of the recent trends on core structures and impact response of sandwich panels. *Journal of Composite Materials*, *55*(18), 2513–2555. https://doi.org/10.1177/0021998321990734

Martin, B. R. (1995). Foresight in science and technology. *Technology Analysis & Strategic Management*, *7*(2), 139–168. https://doi.org/10.1080/09537329508524202

Martin, B. R. (1996). Technology foresight: Capturing the benefits from science-related technologies. *Research Evaluation*, *6*(2), 158–168. https://doi.org/10.1093/rev/6.2.158

McBurney, P., & Parsons, S. (2001). *Reasoning across scenarios in planning under uncertainty*.

McCracken, G. D. (1988). *The long interview*. Sage Publications.

McGowan, P. (2022). *TEACHING TECHNOLOGY FORESIGHT TO BUSINESS AND MANAGEMENT STUDENTS*. 2350–2354. https://doi.org/10.21125/inted.2022.0689

Merton, R. K., Fiske, Marjorie, & Kendall, Patricia L. (1956). *The Focused Interview: A Manual of Problems and Procedures*. Free Press.

Mevlutoglu, A. (2017). Commentary on Assessing the Turkish defense industry: Structural issues and major challenges. *Defence Studies*, *17*(3), 282–294. https://doi.org/10.1080/14702436.2017.1349534

Meza-Mendoza, G. I., Chávez-García, D. H., López Leyva, J. A., & Ponce, M. (2018). Cure Cycle Analysis in Thermoset Polymers by Thermal and Mechanical Analysis. *MRS Advances*, *3*(63), 3811–3816. https://doi.org/10.1557/adv.2018.603

M.F Ashby. (2006). The properties of foams and lattices. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *364*(1838), 15–30. https://doi.org/10.1098/rsta.2005.1678

Miles, I. (2002). *Appraisal of Alternative Methods and Procedures for Producing Regional Foresight*.

Miller, R. (2007). Futures literacy: A hybrid strategic scenario method. *Futures*, *39*(4), 341–362. https://doi.org/10.1016/j.futures.2006.12.001

Milojević, I., & Inayatullah, S. (2015). Narrative foresight. *Futures*, *73*, 151–162. https://doi.org/10.1016/j.futures.2015.08.007

Miodownik, M. (2015). Materials for the 21st century: What will we dream up next? *MRS Bulletin*, *40*(12), 1188–1197. https://doi.org/10.1557/mrs.2015.267

Miranda, A., Leite, M., Reis, L., Copin, E., Vaz, M., & Deus, A. (2021). Evaluation of the influence of design in the mechanical properties of honeycomb cores used in composite panels. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, *235*(6), 1325–1340. https://doi.org/10.1177/1464420720985191

Mohaghar, A., Bazargani, H., Jafarzadeh, A. H., & Soleimani-Sarvestani, M. H. (2013). *Integration of Fuzzy Prioritization Method and TOPSIS for Strategy Ranking*. *6*(5).

Mohammadi, R. (2023). The Role of Strategic Foresight on Dynamic Capabilities. *International Journal of Innovation in Management, Economics and Social Sciences*, *3*(1), 40–45. https://doi.org/10.52547/ijimes.3.1.40

Montibeller, G., Gummer, H., & Tumidei, D. (2006). Combining scenario planning and multi-criteria decision analysis in practice. *Journal of Multi-Criteria Decision Analysis*, *14*(1–3), 5–20. https://doi.org/10.1002/mcda.403

Morgan, D. L. (1997). *Focus groups as qualitative research* (1–16). Sage.

NATO. (2017). *Framework for Future Alliance Operations (FFAO) – Rome Workshop Report* (5000/TSC-PAX-0010/TT-170499 Ser:NU). NATO Defence College.

Nelson, C., Adiguzel, I., Florin, M.-V., Lentzos, F., Knutsson, R., Rhodes, C., Rutten, P., & Vergin, A. (2021). Foresight in Synthetic Biology and Biotechnology Threats. In B. D. Trump, M.-V. Florin, E. Perkins, & I. Linkov (Eds.), *Emerging Threats of Synthetic Biology and Biotechnology* (pp. 177–194). Springer Netherlands. https://doi.org/10.1007/978-94-024-2086-9_12

Nettles, A. T., Barnes, B. W., Guin, W. E., & Mavo, J. P. (2023). The effects of off-axis loading on the compression after impact strength of quasi-isotropic face sheet honeycomb core sandwich structure. *Journal of Sandwich Structures & Materials*, *25*(7), 793–802. https://doi.org/10.1177/10996362231180147

Nordlund, G. (2012). Time-scales in futures research and forecasting. *Futures*, *44*(4), 408–414. https://doi.org/10.1016/j.futures.2012.01.002

Olson, P., Svane, Ö., & Gullström, C. (2021). Mind the gap! Backcasting local actors' climate transition in Hammarby Sjöstad, Stockholm. *Futures*, *128*, 102703. https://doi.org/10.1016/j.futures.2021.102703

Parinov, I. A., Chang, S.-H., & Wang, H.-Y. (2022). Special Issue "Physics and Mechanics of New Materials and Their Applications 2021." *Applied Sciences*, *12*(21), 10941. https://doi.org/10.3390/app122110941

Park, S., & Jun, S. (2022). Patent Analysis Using Bayesian Data Analysis and Network Modeling. *Applied Sciences*, *12*(3), 1423. https://doi.org/10.3390/app12031423

Patil, A. T., Vidhale, B., & Titarmare, A. (2024). Strategic Innovations in Defense Systems: A Comprehensive Analysis of Emerging Technologies and Future Trends. *2024 International Conference on Intelligent Systems for Cybersecurity (ISCS)*, 1–7. https://doi.org/10.1109/ISCS61804.2024.10581013

Patton, M. Q. (2010). *Qualitative research & evaluation methods* (3. ed., [Nachdr.]). Sage.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., Krabel, S., Kitson, M., Llerena, P., Lissoni, F., Salter, A., & Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research Policy*, *42*(2), 423–442. https://doi.org/10.1016/j.respol.2012.09.007

Phaal, R., Farrukh, C. J. P., & Probert, D. R. (2004). Technology roadmapping—A planning framework for evolution and revolution. *Technological Forecasting and Social Change*, *71*(1–2), 5–26. https://doi.org/10.1016/S0040-1625(03)00072-6

Philbin, S. P. (2013). Emerging Requirements for Technology Management: A Sector-based Scenario Planning Approach. *Journal of Technology Management & Innovation*, *8*(3), 7–8. https://doi.org/10.4067/S0718-27242013000400004

Pimentel, J., Castro, J., Perrelli, H., Santos, E., & Franch, X. (2011). Towards anticipating requirements changes through studies of the future. *2011 FIFTH INTERNATIONAL CONFERENCE ON RESEARCH CHALLENGES IN INFORMATION SCIENCE*, 1–11. https://doi.org/10.1109/RCIS.2011.6006858

Popper, R. (2008). How are foresight methods selected? *Foresight*, *10*(6), 62–89. https://doi.org/10.1108/14636680810918586

Qi, C., Jiang, F., & Yang, S. (2021). Advanced honeycomb designs for improving mechanical properties: A review. *Composites Part B: Engineering*, *227*, 109393. https://doi.org/10.1016/j.compositesb.2021.109393

Questel, & Chevalier, B. (2020). Leverage Patent Analytics to Achieve Business-Oriented Objectives: A Pragmatic Approach. *Science Governance and Scientometrics*, *15*(2), 120–135. https://doi.org/10.33873/2686-6706.2020.15-2.120-135

Quist, J. (2003). *Backcasting for Industrial Transformations and System Innovations Towards Sustainability: Relevance for Governance?*

Raj, A., B. Bharath, T. V. Banu Prasad, D. Aakash, & S. V. Madhusudhana. (2024). Designing a Self-healing Composite Material for Aerospace Structural Components. *ACS Journal for Science and Engineering*, *4*(1), 25–38. https://doi.org/10.34293/acsjse.v4i1.103

Rajput, J. K., Patel, K., Srivastava, M., & Kumar, V. (2024). Special Issue on Exploring Material Science and Technology Innovations. *Prabha Materials Science Letters*, *4*(1), 1–3. https://doi.org/10.33889/PMSL.2025.4.1.001

Rathod, V. T., Kumar, J. S., & Jain, A. (2017). Polymer and ceramic nanocomposites for aerospace applications. *Applied Nanoscience*, *7*(8), 519–548. https://doi.org/10.1007/s13204-017-0592-9

Reding, D. F., Martín Blanco, Á., De Lucia, A., Regan, L. A., & Bayliss, D. (2023). *Science & Technology Trends 2023-2043*.

Rinker, M., James Ratcliffe, & Ronald Krueger. (2013). *Analysis of an Aircraft Honeycomb Sandwich Panel with Circular Face Sheet/Core Disbond Subjected to Ground-Air Pressurization* (NASA/CR–2013-217974). https://ntrs.nasa.gov

Robinson, J. B. (1982). Energy backcasting A proposed method of policy analysis. *Energy Policy*, *10*(4), 337–344. https://doi.org/10.1016/0301-4215(82)90048-9

Rohrbeck, R. (2011). *Corporate Foresight*. Physica-Verlag HD. https://doi.org/10.1007/978-3-7908-2626-5

Romanowski, M., & Nadolny, K. (2018). Technological Foresight – characterisation of research methods used in prospective analysis. *Journal of Mechanical and Energy Engineering*, *2*(2), 101–108. https://doi.org/10.30464/jmee.2018.2.2.101

Ryan, S., Hedman, T., & Christiansen, E. L. (2009). *Honeycomb vs. Foam: Evaluating a Potential Upgrade to ISS Module Shielding for Micrometeoroids and Orbital Debris*.

Saaty, T. L. (1980). *The Analytic Hierarchy Process*. McGraw-Hill.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83. https://doi.org/10.1504/IJSSCI.2008.017590

Saaty, T. L., & Vargas, L. G. (2012). *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process* (Vol. 175). Springer US. https://doi.org/10.1007/978-1-4614-3597-6

Salo, A. A., & Hamalainen, R. P. (1997). *PRIME - PREFERENCE RATIOS IN MULTIATTRIBUTE EVALUATION*.

Salo, A., Gustafsson, T., & Ramanathan, R. (2003). Multicriteria methods for technology foresight. *Journal of Forecasting*, *22*(2–3), 235–255. https://doi.org/10.1002/for.850

Salvador, M. R., Zamudio, P. C., Carrasco, A. S. A., Elías Olivares Benítez, & Beatriz Arellano Bautista. (2015). Strategic Foresight: Determining Patent Trends in Additive Manufacturing. *Journal of Intelligence Studies in Business*, *4*(3), 42–62. https://doi.org/10.37380/jisib.v4i3.104

Samareh, J. A., & Siochi, E. J. (2017). Systems analysis of carbon nanotubes: Opportunities and challenges for space applications. *Nanotechnology*, *28*(37), 372001. https://doi.org/10.1088/1361-6528/aa7c5a

Saritas, O., & Aylen, J. (2010). Using scenarios for roadmapping: The case of clean production. *Technological Forecasting and Social Change*, *77*(7), 1061–1075. https://doi.org/10.1016/j.techfore.2010.03.003

Sarjito, A. (2024). Enhancing National Security: Strategic Policy Development in Defense Management. *Jurnal Pelita Nusantara*, *2*(1), 56–68. https://doi.org/10.59996/jurnalpelitanusantara.v2i1.524

Seharing, A., Azman, A. H., & Abdullah, S. (2020). A review on integration of lightweight gradient lattice structures in additive manufacturing parts. *Advances in Mechanical Engineering*, *12*(6), 1687814020916951. https://doi.org/10.1177/1687814020916951

Singh, J., Srivastawa, K., Jana, S., Dixit, C., & S, R. (2024). Advancements in Lightweight Materials for Aerospace Structures: A Comprehensive Review. *Acceleron Aerospace Journal*, *2*(3), 173–183. https://doi.org/10.61359/11.2106-2409

Slaughter, R. A. (1996a). *Futures Studies: From Individual to Social Capacity*.

Slaughter, R. A. (1996b). *Futures Studies: From Individual to Social Capacity*.

Sobhy, M., & Al Mukahal, Fatemah. H. H. (2023). Magnetic Control of Vibrational Behavior of Smart FG Sandwich Plates with Honeycomb Core via a Quasi-3D Plate Theory. *Advanced Engineering Materials*, *25*(13), 2300096. https://doi.org/10.1002/adem.202300096

Spaniol, M. J. (2024). Organizing Foresight Tools. *World Futures Review*, *16*(3), 261–276. https://doi.org/10.1177/19467567241262951

SSB. (2024). *2024 Composite OTAĞ Final Report*. Presidency of Defence Industries (SSB).

Surve. (2014). Study of Technology Forecasting Methods. *International Journal of Emerging Trends in Science and Technology*.

Tancogne-Dejean, T., Diamantopoulou, M., Gorji, M. B., Bonatti, C., & Mohr, D. (2018). 3D Plate-Lattices: An Emerging Class of Low-Density Metamaterial Exhibiting Optimal Isotropic Stiffness. *Advanced Materials*, *30*(45), 1803334. https://doi.org/10.1002/adma.201803334

Terziev, V., & Bogdanova, M. (2019). STRATEGIC AND FINANCIAL FRAME OF INTERVENTION- CENTERS OF EXCELLENCE AND CENTERS OF COMPETENCE. *IJASOS- International E-Journal of Advances in Social Sciences*, 156–167. https://doi.org/10.18769/ijasos.531381

The Futures Toolkit: Tools for Futures Thinking and Foresight across UK Government. (n.d.).

Thorén, K., & Vendel, M. (2019). Backcasting as a strategic management tool for meeting VUCA challenges. *Journal of Strategy and Management*, *12*(2), 298–312. https://doi.org/10.1108/JSMA-10-2017-0072

Tran, T. A., & Daim, T. (2008). A taxonomic review of methods and tools applied in technology assessment. *Technological Forecasting and Social Change*, *75*(9), 1396–1405. https://doi.org/10.1016/j.techfore.2008.04.004

UK Health and Safety Executive. (2023). *Future of energy: Three Horizons, Futures Wheels*. GOV.UK. https://www.gov.uk/government/publications/future-of-energy-three-horizons-and-futures-wheels-health-and-safety-executive/future-of-energy-three-horizons-futures-wheels

UN Global Pulse. (n.d.). *Futures Wheel*. UNGP - Foresight Project. Retrieved April 13, 2025, from https://foresight.unglobalpulse.net/blog/tools/futures-wheel/

Vecchiato, R., Favato, G., Di Maddaloni, F., & Do, H. (2020). Foresight, cognition, and long-term performance: Insights from the automotive industry and opportunities for future research. *FUTURES & FORESIGHT SCIENCE*, *2*(1), e25. https://doi.org/10.1002/ffo2.25

Velasquez, M., & Hester, P. T. (2013). *An Analysis of Multi-Criteria Decision Making Methods*. *10*(2).

Voros, J. (2003). A generic foresight process framework. *Foresight*, *5*(3), 10–21. https://doi.org/10.1108/14636680310698379

Wang, G., Yu, C., MacFarlane, D., & Zhao, H. (2020). Materials Science in Australia. *Advanced Materials*, *32*(18), 2001629. https://doi.org/10.1002/adma.202001629

Wang, H., Lu, Z., Yang, Z., & Li, X. (2019). In-plane dynamic crushing behaviors of a novel auxetic honeycomb with two plateau stress regions. *International Journal of Mechanical Sciences*, *151*, 746–759. https://doi.org/10.1016/j.ijmecsci.2018.12.009

Wiebe, K., Zurek, M., Lord, S., Brzezina, N., Gabrielyan, G., Libertini, J., Loch, A., Thapa-Parajuli, R., Vervoort, J., & Westhoek, H. (2018). Scenario Development and Foresight Analysis: Exploring Options to Inform Choices. *Annual Review of Environment and Resources*, *43*(1), 545–570. https://doi.org/10.1146/annurev-environ-102017-030109

Will Hartigan & Arthur Horobin. (2024). *Policy Fit for the Future*. Department of the Prime Minister and Cabinet, Commonwealth of Australia.

Williams, T. S. (2019). *Multifunctional Polymers and Composites for Aerospace Applications*.

Wilson, C., Tansey, J., & LeRoy, S. (2006). *Integrating Backcasting & Decision Analytic Approaches to Policy Formulation: A Conceptual Framework.*

Yıllıkçı, K., & Findik, F. (2013). A Survey of Aircraft Materials: Design for Airworthiness and Sustainability. *Periodicals of Engineering and Natural Sciences (PEN)*, *1*(1). https://doi.org/10.21533/pen.v1i1.13

Yu, H., Hu, X., Kong, L., & Yu, B. (2019). Process path planning based on efficiency model for ultrasonic cutting curved surface of honeycomb composite parts. *Advances in Mechanical Engineering*, *11*(10), 1687814019884176. https://doi.org/10.1177/1687814019884176

Yüksel, N. (2018). *A New Technology Foresight Model and Its Application in Turkish Defense Industry for Aerospace Communication Technologies of 2040* [Doctoral dissertation]. Middle East Technical University.

Yuksel, N., & Cifci, H. (2017). A new model for technology foresight: Foresight periscope model (FPM). *2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, 807–817. https://doi.org/10.1109/ICE.2017.8279967

Zaaba, N. F., Ismail, H., & Saeed, A. M. (2021). A Review: Metal Filled Thermoplastic Composites. *Polymer-Plastics Technology and Materials*, *60*(10), 1033–1050. https://doi.org/10.1080/25740881.2021.1882489

Zenkert, D. (1995). *An Introduction to Sandwich Construction*. EMAS Publishing.

Zhang, Q., Yang, X., Li, P., Huang, G., Feng, S., Shen, C., Han, B., Zhang, X., Jin, F., Xu, F., & Lu, T. J. (2015). Bioinspired engineering of honeycomb structure – Using nature to inspire human innovation. *Progress in Materials Science*, *74*, 332–400. https://doi.org/10.1016/j.pmatsci.2015.05.001

Zhang, Y., Chen, T., Xu, X., & Hu, Z. (2020). Out-of-plane mechanical behaviors of a side hierarchical honeycomb. *Mechanics of Materials*, *140*, 103227. https://doi.org/10.1016/j.mechmat.2019.103227

Zhou, K. (2021). Composite Materials and Their Fiber Reinforcement Technology in Aerospace Field. *Scientific and Social Research*, *3*(1). https://doi.org/10.36922/ssr.v3i1.1074

Zhu, X., Meng, X., & Zhang, M. (2021). APPLICATION OF MULTIPLE CRITERIA DECISION MAKING METHODS IN CONSTRUCTION: A SYSTEMATIC LITERATURE REVIEW. *JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT*, *27*(6), 372–403. https://doi.org/10.3846/jcem.2021.15260

Zionts, S. (1979). MCDM—If Not a Roman Numeral, Then What? *Interfaces*, *9*(4), 94–101. https://doi.org/10.1287/inte.9.4.94

Zionts, S., & Wallenius, J. (1976). An Interactive Programming Method for Solving the Multiple Criteria Problem. *Management Science*, *22*(6), 652–663. https://doi.org/10.1287/mnsc.22.6.652

(2017, April 13). What Is Materials Technology at NTNU? https://www.ntnu.edu/ima/about-us/what-is-materials-technology

(2023, December 19). https://mpe.au.dk/en/research/key-areas-in-research-and-development/mechanics-and-materials-mechnical-and-production-engineering-technical-sciences-aarhus-university/materials-technology

APPENDICES

A. NOTATION SUMMARY FOR AHP METHOD

Symbol / Term	Meaning
A	Pairwise comparison matrix
a_{ij}	Relative importance of criterion *i* over *j*
$a_{ij} = 1$	Diagonal values; importance of criterion with itself
w_i	Priority weight (importance score) for criterion *i*
λmax	Maximum eigenvalue of matrix AA
CI	Consistency Index
RI	Random Consistency Index (table-provided)
CR	Consistency Ratio, i.e., CIRI\frac{CI}{RI}
w_i^k	Weight assigned to criterion *i* by expert *k*
m	Number of experts
n	Number of criteria
$w_i^{normalized}$	Final normalized weight for criterion *i*

B. METU HUMAN SUBJECTS ETHICS COMMITTEE APPROVAL LETTER

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

12 MAYIS 2025

Konu : Değerlendirme Sonucu
Gönderen : ODTÜ İnsan Araştırmaları Etik Kurulu
İlgi : İnsan Araştırmaları Etik Başvurunuz

Sayın Prof. Dr. Mehmet Teoman Pamukçu,
Sayın Gül Beyza Kocamış,

"Savunma ve havacılık sanayisinde geleceğe yönelik öngörü temelli politika geliştirme: Balpeteği malzeme teknolojisi örneği" başlıklı araştırmanız ODTÜ İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0211-ODTÜİAEK-2025 protokol numarası ile onaylanmıştır.

Bilgilerinize sunarım.

Prof. Dr. Ş. Halil TURAN
Başkan

Prof. Dr. İ. Semih AKÇOMAK
Üye

KATILMADI
Doç. Dr. Ali Emre TURGUT
Üye

Doç. Dr. Aslı Kılıç ÖZHAN
Üye

KATILMADI
Doç. Dr. Murat Perit ÇAKIR
Üye

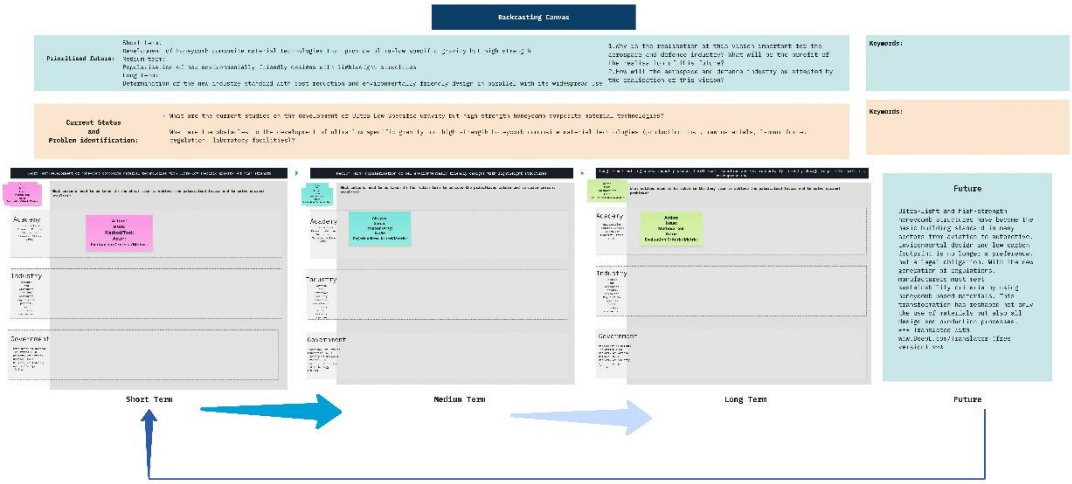
Doç. Dr. Duygu SARISOY
Üye
(İzinli)

Dr. Öğr. Üyesi Müge GÜNDÜZ
Üye

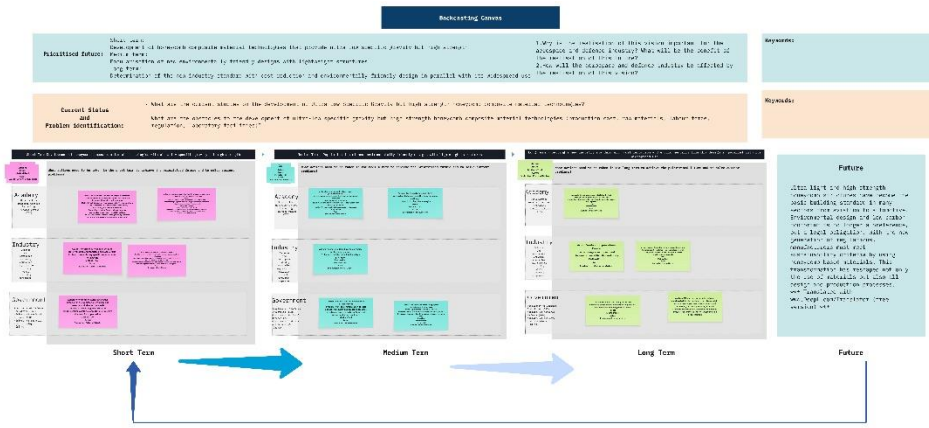
C. INTERVIEW GUIDE FOR BACKCASTING FOCUS GROUP

Phase	Focus	Question Theme	Questions (asked directly to participants)
1	Understanding the prioritized path	Importance of the Future Vision	Why is the realization of this future vision important? What potential benefits could it bring for the aerospace and defense sectors?
2	Understading the needs	Current State & Problem Identification	Are there any existing initiatives or efforts that support this future vision today? What are the main barriers currently preventing progress toward this future?
3	Backcasting-based policy development in the context of the Triple Helix model.	Short-Term Actions *(0–5 years)*	What concrete actions should be taken in the short term to enable this prioritized future and address the identified problems? (Please provide your suggestions separately for each of the following stakeholders: **Academia**, **Industry**, and **Government**.)
4		Medium-Term Actions *(5–10 years)*	After initial steps are taken, what actions should be implemented in the medium term? (Please provide your suggestions separately for each of the following stakeholders: Academia, Industry, and Government.)
5		Long-Term Actions *(10+ years)*	What actions should be implemented in the long term? (Please provide your suggestions separately for each of the following stakeholders: Academia, Industry, and Government.)

D. BACKCASTING CANVAS TEMPLATE (MIRO BOARD)



E. FINAL VERSION OF BACKCASTING CANVAS (MIRO BOARD)



F. TURKISH SUMMARY / TÜRKÇE ÖZET

Teknolojik gelişmelerin hızla ilerlediği savunma ve havacılık sanayisinde, uzun vadeli kararların yalnızca bugünkü teknolojiye değil, gelecekteki potansiyel gelişmelere de dayanması gerekir. Bu nedenle öngörü temelli yöntemler, uzun vadeli planlamada giderek daha önemli hale gelmektedir. Bu tez, savunma ve havacılık sanayisinde yüksek öneme sahip malzeme teknolojilerinden biri olan balpeteği yapılı kompozitlerin geleceğini öngörüye dayalı senaryo geliştirme ve politika üretme süreçleri aracılığıyla incelemekte, Türkiye'nin uzun vadeli planlama ekosistemine katkı sağlayabilecek öngörü temelli bir yöntemsel karar verme süreci ortaya koymaktadır. Tez, balpeteği malzemelerini bir vaka çalışması olarak ele almaktadır. Bu yaklaşım, savunma ve havacılık sanayiinde uzun vadeli planlama bağlamında pek çok farklı konuda uygulama alanı bulabilecek niteliktedir.

Malzeme bilimi, tarihsel olarak teknolojik yeniliklerin en kritik alanlarından birini temsil etmiş, savunma ve havacılık sektörleri ise bu gelişmelerin öncüsü olmuştur. Özellikle ağırlık azaltma, dayanım artırma ve sürdürülebilirlik gibi performans ölçütleri, savunma platformlarının rekabet gücünü belirleyen başlıca unsurlar arasında sayılmaktadır. Bu bağlamda, ileri malzeme teknolojilerinin önemli bir örneğini oluşturan balpeteği malzeme teknolojisi, sundukları avantajlar sayesinde havacılık ve savunma sanayinde giderek artan bir öneme sahip olmuş, aynı zamanda hem askeri hem de sivil uygulamalarda çift kullanımlı potansiyelleriyle öne çıkmıştır. Doğadan ilham alan altıgen geometrileri sayesinde yüksek dayanımı düşük ağırlıkla birleştiren bu yapılar, yalnızca uçak gövdesi ve kanat panellerinde değil, zırh sistemlerinde enerji emme kapasiteleriyle de kullanılmaktadır (Qi et al., 2021). Bu özellikleri, balpeteği malzemelerini geleceğin savunma platformlarında kritik bir bileşen haline getirmektedir.

Türkiye özelinde, ileri malzeme alanında son yıllarda yerli üretim kabiliyetlerinin güçlendirilmesi ve dışa bağımlılığın azaltılmasına yönelik önemli adımlar atılmıştır.

Örneğin, TÜBİTAK'ın yönlendirdiği araştırma projeleri ve ASELSAN, TUSAŞ, Roketsan gibi kurumların kurduğu Ar-Ge merkezleri, yerli karbon fiber ve polimer matrisli kompozitlerin geliştirilmesini stratejik bir hedef haline getirmiştir. Ayrıca, Savunma Sanayii Başkanlığı'nın (SSB, 2024) vizyon raporlarında, balpeteği çekirdekli(core) kompozitlerin yerli sistemlerde kullanılmasının kritik öncelikler arasında olduğu açıkça vurgulanmaktadır. Ancak, savunma sanayiinde kullanılan ileri malzemeler konusunda uzun vadeli, öngörü temelli politika geliştirme uygulamalarının sınırlı kaldığı görülmektedir. Bu eksiklik, geleceğe yönelik teknolojik yol haritalarının oluşturulmasını zorlaştırmakta ve karar alıcıların çoğunlukla kısa vadeli ihtiyaçlara odaklanmasına neden olmaktadır. İşte bu noktada tez, söz konusu boşluğu ele almakta; yapılandırılmış bir öngörü metodolojisi ortaya koyarak savunma sanayiinde yenilikçi bir politika geliştirme yaklaşımı sunmaktadır. Böylelikle, belirsiz bir gelecekte karar almak isteyen politika yapıcılara uygulanabilir bir yöntem önerilmekte; aynı zamanda Türkiye'nin savunma planlama ekosisteminde uzun vadeli öngörüye dayalı yaklaşımların gelişimine katkıda bulunmaktadır.

Bu çerçevede, tezin amacı balpeteği malzemelerinin Türkiye savunma ve havacılık sektöründeki geleceğini belirlemek ve bu gelecek senaryolarının gerçekleşmesini destekleyecek politika önerileri geliştirmektir. Bu doğrultuda iki temel araştırma sorusu formüle edilmiştir: (1) Balpeteği malzeme teknolojilerinin savunma ve havacılık sanayisindeki öncelikli geleceği nedir? (2) Bu geleceğin gerçekleşmesini sağlamak için hangi politika araçları gereklidir? Araştırma sürecinde bu sorulara yanıt aramak üzere keşifsel ve normatif yaklaşımlar bir arada kullanılmıştır. Öncelikle mevcut eğilimler ve teknolojik gelişmelerin yönünü anlamaya yönelik keşifsel analizler yapılmış, ardından arzulanan geleceğe ulaşmak için bugünden atılması gereken adımlar normatif olarak tartışılmıştır.

Araştırma soruları ile uyumlu olacak şekilde, hem nicel hem de nitel teknikleri içeren karma yöntem yaklaşımı benimsenmiştir. Bu yaklaşım, nitel bulguların nicel olarak ölçülebilir hale gelmesini, sayısal verilerin bağlamsal anlayışla zenginleştirilmesini, tekil yöntemlerin gözden kaçırabileceği farklı açılardan araştırma sorularının ele alınmasını ve elde edilen sonuçların hem güvenilirliğinin hem de uygulanabilirliğinin artırılmasını sağlamaktadır (Creswell, 2022). Yöntemsel ilerleme özellikle öngörünün

ikili doğasını yansıtacak biçimde kurgulanmıştır: olası gelecekleri keşfetmek (keşifsel) ve arzu edilen bir sonuca ulaşmak için gerekli politika önerilerini belirlemek (normatif). Bu doğrultuda, keşifsel ve normatif yöntemlerin bir araya getirilmesiyle politika yapımına yönelik "eyleme dönüştürülebilir bilgi" üretilmesi amaçlanmaktadır (Popper, 2008). Eyleme dönüştürülebilir bilgi uzman yargısına, yapılandırılmış öngörü çıktıları ile önceliklendirilmiş gelecek senaryolarına dayanan ve karar alıcılara somut yol gösterici nitelikte politika ile ilgili içgörüler anlamına gelmektedir.

Keşifsel aşamada Futures Wheel **(**Gelecekler Çarkı**)** yöntemi kullanılmıştır. Jerome C. Glenn tarafından 1971'de geliştirilen Gelecekler Çarkı, belirli bir olay veya teknolojik gelişmenin doğrudan ve dolaylı etkilerini sistematik biçimde haritalandırmaya yarayan görsel ve analitik bir tekniktir (Glenn, 2009). Literatürde, bu yöntemin çok katmanlı sonuçları görselleştirmedeki gücü sayesinde senaryo kurgulamada ve politika süreçlerinde yaygın olarak kullanıldığı vurgulanmaktadır (Slaughter, 1996; Bengston, 2016). Ayrıca, NATO (2017) ve Birleşmiş Milletler gibi uluslararası kurumların resmi öngörü araç setlerine dâhil edilerek stratejik karar süreçlerinde uygulanması, yöntemin politika oluşturmada değerini göstermektedir. Bu tez kapsamında Gelecekler Çarkı, balpeteği malzemelerinin savunma ve havacılık sanayiindeki muhtemel etkilerini sistematik biçimde ortaya koymak ve alternatif gelecek patikaları inşa etmek amacıyla tercih edilmiştir.

Normatif aşamada ise Backcasting (Tersgörü) yöntemi uygulanmıştır. John B. Robinson tarafından 1980'lerde enerji politikalarının şekillendirilmesinde kullanılan bir planlama yaklaşımı olarak tanımlanan Tersgörü, arzu edilen bir gelecek durumdan geriye doğru hareket ederek bu geleceğe ulaşmak için gerekli adımları ve politika araçlarını belirlemeye odaklanmaktadır (Robinson, 1982; Dreborg, 1996). Literatürde, sürdürülebilirlik, şehircilik ve teknoloji politikalarında uzun vadeli dönüşümleri tasarlamak için sıklıkla başvurulduğu belirtilmektedir (Wilson et al., 2006; Bengston et al., 2020). Bu bağlamda, tezde önceliklendirilen gelecek patikasına ulaşmak için gerekli politika önerilerinin geliştirilmesi amacıyla Tersgörü yöntemi kullanılmış, böylece normatif vizyonun kısa, orta ve uzun vadeli eylemlerle nasıl hayata geçirilebileceği sistematik biçimde incelenmiştir.

Araştırma tasarımının metodolojik akışı, öngörü yaklaşımını destekleyecek şekilde yapılandırılmıştır. Bu kapsamda, vaka seçimini doğrulamak amacıyla girdi aşaması niteliğinde bir patent analizi gerçekleştirilmiş ve elde edilen bulgular sonraki aşamalara girdi sağlayan bir doğrulama adımı olarak kurgulanmıştır. Analiz, balpeteği yapılı malzemelerle ilgili son on yılda alınmış yüzlerce patenti incelemiş ve bu alandaki yeniliklerin hâlen güçlü biçimde devam ettiğini göstermiştir. Özellikle 2005 sonrası hızla artan başvurular, balpeteği teknolojilerinin havacılık ve savunma sektörleri için yalnızca geçmişte değil, günümüzde ve gelecekte de stratejik önem taşıdığını ortaya koymuştur. Böylece, balpeteği yapılarının tez kapsamında vaka olarak seçilmesi hem literatür hem de güncel teknoloji eğilimleriyle desteklenmiştir.

Birinci temel aşamada Gelecekler Çarkı yöntemi uygulanmış ve bu süreç üç alt aşamada kurgulanmıştır.

İlk alt adımda, balpeteği malzemelerinin geleceğini değerlendirmek üzere çok kriterli bir değerlendirme geliştirilmiştir. Bu çerçevede kriterler, literatür taraması, uzman görüşleri ve savunma-havacılık sektörünün stratejik öncelikleri dikkate alınarak belirlenmiştir. Özellikle "geleceğe etki düzeyi", "operasyonel uygulama alanları" ve "çift kullanımlı potansiyel" gibi kriterler ön plana çıkarılmıştır. Bu kriterler hem teknolojik yeniliklerin somut etkilerini hem de sektörler arası geçişkenliği ölçmeye imkân tanıyacak biçimde yapılandırılmıştır.

İkinci alt adımda, Gelecekler Çarkı çıktılarının sistematik biçimde ele alınabilmesi için bir puanlama ve patika değerlendirme yöntemi kurgulanmıştır. Bu aşamada amaç, odak grup oturumunda üretilen çok sayıda öngörü ifadesinin hangi çerçevede değerlendirileceğini belirlemek ve sonraki analizlere metodolojik bir tutarlılık kazandırmaktır. Bu kapsamda, öngörü ifadelerinin değerlendirilmesinde kullanılacak kriter seti ile bu kriterlere nasıl ağırlık verileceği önceden tasarlanmıştır. Özellikle, alan uzmanlarından toplanacak puanların Analitik Hiyerarşi Süreci (AHP) yöntemiyle hesaplanan kriter ağırlıklarıyla birleştirilmesi planlanmıştır. Ayrıca, öngörülerin kısa (0–5 yıl), orta (5–10 yıl) ve uzun vadeli (10+ yıl) zaman ufuklarına dağılımı da metodun içine dâhil edilerek, gelecek patikalarının hem içeriksel hem de zamansal boyutta dengeli biçimde ele alınması sağlanmıştır. Böylelikle bu alt adım, Gelecekler

Çarkı çıktılarının yalnızca nitel bir betimleme olmaktan çıkıp sistematik bir çerçeve içinde değerlendirilebilmesine yönelik bir yöntemsel altyapı oluşturmuştur.

Üçüncü alt adımda, Gelecekler Çarkı odak grup çalışması gerçekleştirilmiştir. Bu çalışma, Triple Helix (Üçlü Sarmal) Modeli çerçevesinde sanayi, kamu ve akademi temsilcilerinin bir araya getirilmesiyle çok aktörlü bir öngörü sürecinin yürütülmesini sağlamıştır. Bu aşama aynı zamanda, ikinci adımda kurgulanan metodun verilerle bütünleştirilmesini mümkün kılmıştır. Çevrimiçi olarak gerçekleştirilen oturumda, bu yöntem için özel olarak geliştirilen bir web arayüzü kullanılmıştır. Katılımcılar bu arayüz üzerinden belirlenen kriterlere göre öngörü ifadelerini puanlamış, farklı perspektiflerini sürece yansıtarak mantıksal bütünlük içinde gelecek patikalarının şekillendirilmesine katkıda bulunmuştur. Burada kullanılan arayüz, yalnızca bu çalışmaya özgü bir uygulama değil, aynı zamanda benzer öngörü süreçlerinde de kolayca uyarlanabilecek nitelikte bir araç olarak tasarlanmıştır. Oturum sonunda toplam 52 öngörü ifadesi üretilmiş; bu ifadeler kısa, orta ve uzun vadeli zaman ufuklarına yerleştirilerek 10 tam gelecek patikasına dönüştürülmüştür. İlk ve ikinci alt adımda oluşturulan metodoloji ile üçüncü alt adımda elde edilen bilgilerin analiz edilmesi sonucunda patikalar arasında en yüksek önceliğe sahip patika belirlenmiş ve böylece Gelecekler Çarkı aşaması, araştırmanın ikinci aşaması olan Tersgörü sürecine doğrudan girdi sağlayan somut bir çıktıyla tamamlanmıştır.

İlk temel aşama olan Gelecekler Çarkı aşaması sonucunda kısa vadede ultra hafif ve yüksek dayanımlı kompozit balpeteği yapılarının geliştirilmesi, orta vadede çevre dostu tasarımların yaygınlaşması ve uzun vadede maliyetlerin düşmesiyle birlikte sürdürülebilir endüstri standartlarının oluşması öngörülen bir yol en yüksek öncelikli senaryo olarak belirlenmiştir. İkinci aşamada öncelikli gelecek yolu, Miro platformu üzerinde zaman ufuklarına göre aktör-temelli politika adımlarına dönüştürülmüş ve veriler nitel kodlama yöntemiyle analiz edilmiştir. Bu aşamada üretilen nitel veriler, Refleksif Tematik Analiz (RTA) yaklaşımıyla, MAXQDA yazılımı kullanılarak tümevarımsal kodlama yöntemiyle incelenmiştir. Katılımcıların kendi ifadelerinden türeyen ve önceden tanımlı bir çerçeveden bağımsız olarak ortaya çıkan 80'in üzerinde kodlanmış bölüm belirlenmiştir. Böylelikle araştırma tasarımı, keşifsel Gelecekler

Çarkı aşamasından başlayarak normatif Tersgörü aşamasına uzanan bütüncül bir süreç olarak tamamlanmıştır.

Bu bütüncül süreç sonunda, Tersgörü oturumundan dört tema altında toplanan 16 politika önerisi geliştirilmiştir. Bu dört ana tema ve bulgular aşağıda belirtilmiştir.

Teknoloji geliştirme: Katılımcılar, balpeteği yapılarının mevcut potansiyelini aşmak için özellikle hibrit geometrilerin (altıgenin ötesine geçen topolojik çeşitlilik) araştırılması gerektiğini vurgulamışlardır. Ayrıca, 3B baskı tabanlı özelleştirilmiş balpeteği çekirdekleri sayesinde operasyonel yük koşullarına uygun, uygulamaya özel çözümler üretilebileceği öne sürülmüştür. Bu bağlamda termoplastik balpeteği çekirdeklerinin geliştirilmesi kısa vadeli bir Ar-Ge önceliği olarak belirlenmiş, sürdürülebilirlik ve hafiflik kriterlerini birlikte sağlayan yenilikçi çözümlere kapı aralayacağı öngörülmüştür. Katılımcılar bu önerilerin, literatürde son yıllarda giderek artan biçimde tartışılan "geometri odaklı malzeme tasarımı" eğilimiyle uyumlu olduğunu da belirtmiş, yapısal performansın yalnızca malzeme kompozisyonu ile değil, aynı zamanda hücre mimarisi ve topolojik çeşitlilik ile de yönlendirilebileceğini dile getirmişlerdir.

Araştırma ve uygulama arasındaki köprünün kurulması: Savunma ve havacılıkta malzeme teknolojilerinin hızla sertifikasyon ve uygulama aşamasına geçmesi gerektiği için, üniversite laboratuvarlarında üretilen bulguların prototipe dönüştürülmesini kolaylaştıracak mekanizmalar önerilmiştir. Ayrıca, kamu tarafından desteklenecek Mükemmeliyet Merkezleri kurulması gerektiği dile getirilmiştir. Bu merkezler hem standart test altyapısı sağlayarak üniversite–sanayi iş birliğini kurumsallaştıracak hem de kritik malzeme geliştirme projelerini doğrudan sanayiye aktararak yaygınlaştırma işlevi üstlenecektir. Bu öneri, katılımcıların sıkça dile getirdiği bir soruna, yani üniversitede geliştirilen çözümlerin laboratuvar ölçeğinde kalması ve endüstriye aktarılamaması sorununa yanıt olarak öne çıkmıştır. Dolayısıyla, Mükemmeliyet Merkezleri yalnızca teknik bir test altyapısı değil, aynı zamanda bilgi akışını hızlandıracak ve Ar-Ge çıktılarını ürünleştirmeyi kolaylaştıracak bir kurumsal araç olarak konumlanmıştır.

Yerli üretim kapasitesinin geliştirilmesi: Katılımcılar, Türkiye'de balpeteği yapılı kompozitlerin üretim kapasitesinin sınırlı olduğuna dikkat çekmiş ve yerli üreticilerin desteklenmesine yönelik politikalara ihtiyaç olduğunu belirtmiştir. Bu kapsamda, savunma projelerinde yerli malzeme kullanımının adım adım zorunlu hale getirilmesi, tedarik ve sertifikasyon süreçlerinde yerli üreticilerin önceliklendirilmesi ve piyasa talebinin net biçimde analiz edilerek yerli sanayiye aktarılması gibi öneriler öne çıkmıştır. Böylece yalnızca Ar-Ge düzeyinde kalmayan, doğrudan endüstriyel ölçeklenebilirliği hedefleyen bir politika çerçevesi şekillenmiştir. Özellikle katılımcılar, bu tür politikaların yalnızca savunma sanayiinde dışa bağımlılığı azaltmayacağını, aynı zamanda yeni girişimlerin pazara girmesi için teşvik edici bir ortam yaratacağını da vurgulamışlardır. Böylece, yerli sanayinin küresel ölçekte rekabet edebilirliği artırılabilecektir.

Sürdürülebilirlik ve çevresel etkiler: Çalışmada, geri dönüştürülebilir termoplastiklerin yaygınlaştırılması ve çevresel etki kriterlerinin savunma projelerinin tüm aşamalarına entegre edilmesi gerektiği vurgulanmıştır. Ayrıca, uzun vadede yeşil endüstri standartlarının oluşturulması, karbon emisyonlarının azaltılması ve çevre dostu tasarımların yaygınlaşması için somut adımlar atılması önerilmiştir. Katılımcılar, özellikle havacılık sektöründe ağırlık azaltmanın doğrudan yakıt tüketimi ve CO_2 emisyonlarıyla ilişkili olduğunu vurgulamış, bu nedenle balpeteği yapılı kompozitlerin çevresel sürdürülebilirlik boyutuyla da stratejik önem taşıdığını ortaya koymuştur. Bu bağlamda, termoplastik kompozitlerin hem geri dönüştürülebilirliği hem de hafifliği bir arada sunma potansiyeli, sektör için yeni bir paradigma olarak görülmüş ve gelecekte sürdürülebilirlik kriterlerinin artık opsiyonel değil, zorunlu bir standart haline geleceği ifade edilmiştir.

Katılımcıların Tersgörü oturumundaki katkılarıyla toplam 16 politika önerisi geliştirilmiştir. Bu öneriler yalnızca tematik başlıklar altında sıralanmakla kalmamış, aynı zamanda kısa, orta ve uzun vadeli zaman ufuklarına göre yapılandırılarak uygulanabilirliği güçlendirilmiştir. Ayrıca, her bir öneri aktör-temelli biçimde (kamu, sanayi, akademi) dağıtılmış ve hangi tarafın hangi dönemde hangi sorumlulukları üstleneceği tanımlanmıştır. Bu yaklaşım, araştırmanın yalnızca teorik bir çerçeve sunmakla sınırlı kalmayıp aynı zamanda uygulanabilir politika önerileri önermeyi amaçladığını göstermektedir.

Kısa vadeli politika önerileri (0–5 yıl) ağırlıklı olarak mevcut yapısal boşlukların giderilmesine ve kritik teknolojik açığın kapatılmasına odaklanmaktadır. Bu kapsamda, termoplastik balpeteği yapılarının Ar-Ge yoluyla geliştirilmesi, savunma ve havacılık platformlarının ihtiyaçlarına özgü performans kriterlerinin sistematik biçimde tanımlanması, klasik altıgen yapıların ötesine geçen hibrit topolojilerin araştırılması ve en önemlisi, hâlen Türkiye'de bulunmayan yerli üretici tabanının oluşturulması temel öncelikler olarak öne çıkmıştır. Bu dönemde önerilen politikalar, hem bilimsel bilgi üretimini hem de sanayi ölçeğinde üretim altyapısının kurulmasını aynı anda hedeflemektedir. Kısa vadeli önerilerin ortak eğilimi, dışa bağımlılığı azaltacak ilk adımların hızla atılması, yerli aktörlerin sisteme dâhil edilmesi ve teknoloji geliştirme süreçlerinin kritik yol haritalarıyla desteklenmesidir.

Orta vadeli politika önerileri (5–10 yıl) daha çok araştırma ve uygulama arasındaki köprüyü güçlendirmeyi ve kurumsal yapıları kalıcı hale getirmeyi amaçlamaktadır. Bu aşamada, üniversitelerde geliştirilen termoplastik balpeteği çekirdeklerinin sanayiye aktarılması için yapılandırılmış prototipleme ve doğrulama programlarının uygulanması, geri dönüştürülebilir kompozitlerin geliştirilmesi, robotik üretim teknolojilerinin devreye alınması ve performans doğrulaması için simülasyon araçlarının yerli imkânlarla tasarlanması öne çıkmaktadır. Ayrıca, ulusal mükemmeliyet merkezlerinin kurulması, kapsamlı bir malzeme veritabanı ve katalog sisteminin oluşturulması, standardizasyon ve açık veri temelli doğrulama altyapılarının hayata geçirilmesi orta vadeli önerilerin kurumsal boyutunu oluşturmaktadır. Bu sayede, kısa vadede başlatılan Ar-Ge faaliyetleri sanayiye taşınmakta, kurumsallaşmakta ve ulusal ölçekte sürdürülebilir bir ekosistem inşa edilmektedir. Orta vadeli önerilerin genel eğilimi, yenilikçi araştırma sonuçlarının ticarileştirilmesi, sanayinin ihtiyaç duyduğu test–sertifikasyon altyapısının güçlendirilmesi ve politika yapımında koordinasyon mekanizmalarının kurulmasıdır.

Uzun vadeli politika önerileri (10 yıl ve sonrası) ise balpeteği yapılı malzemelerin ileri teknolojik yetkinliklerle donatılması ve sürdürülebilirlik odaklı küresel standartların oluşturulmasına yöneliktir. Bu aşamada, platforma özgü yük koşullarına adapte olabilen gelişmiş 3B kafes yapıların tasarımı, balpeteği malzemelerin akustik izolasyon gibi çok işlevli özelliklerle zenginleştirilmesi, uzun vadeli performansın

güvence altına alınması için ulusal sertifikasyon prosedürlerinin geliştirilmesi ve çevresel etki kriterlerinin malzeme geliştirme süreçlerine sistematik olarak entegre edilmesi öngörülmektedir. Ayrıca, tüm bu süreçlerin ortak bir dijital altyapı üzerinden yönetilmesi, verilerin paylaşılması ve simülasyon–sertifikasyon çıktılarının merkezi bir platformda toplanması uzun vadeli vizyonun tamamlayıcı unsurlarını oluşturmaktadır. Uzun vadeli önerilerin genel eğilimi, teknolojik kapasiteyi küresel rekabet gücü sağlayacak biçimde ileriye taşımak, sürdürülebilirlik ilkelerini stratejik bir zorunluluk haline getirmek ve savunma–havacılık ekosisteminde dijitalleşmeyi kurumsal bir standart olarak yerleştirmektir.

Böylelikle tez, keşifsel bir öngörü metodu olan Gelecekler Çarkı aşamasında ortaya çıkan öngörüleri sistematik biçimde önceliklendirerek, Tersgörü sürecinde bunları uygulanabilir politika önerilerine dönüştürmüş ve karar alıcılar için izlenebilir, zamanlaması net ve sorumlulukları tanımlanmış bir yol haritası sunmuştur.

Bu bulguların bütüncül olarak değerlendirilmesi, yalnızca balpeteği yapılı kompozitlerin teknik potansiyeline ışık tutmakla kalmayıp aynı zamanda Türkiye'nin savunma ve havacılık planlamasında geleceğe dönük düşünme biçimlerinin nasıl kurumsallaştırılabileceğine dair kapsamlı öngörüler sunmaktadır. Tezde kullanılan öngörü yöntemleri, bir yandan teknolojik eğilimlerin sistematik biçimde haritalandırılmasına olanak vermiş, diğer yandan bu eğilimlerin politika düzeyinde nasıl anlamlandırılabileceğini göstermiştir. Bu yönüyle çalışma, hem bilimsel araştırma literatürüne hem de pratik savunma planlaması uygulamalarına çift yönlü katkı sağlamaktadır.

Ortaya konulan senaryolar ve politika önerileri, özellikle belirsizliklerin yüksek olduğu savunma teknolojileri gibi alanlarda karar vericiler için önemli bir yol gösterici nitelik taşımaktadır. Çünkü malzeme teknolojilerinde bugün alınacak stratejik kararlar, yalnızca kısa vadeli projelerin başarısını değil, aynı zamanda önümüzdeki on yılların rekabetçi konumunu da belirleyecektir. Bu nedenle tez kapsamında geliştirilen yöntemsel yaklaşım, yalnızca akademik bir araştırma olmanın ötesinde, doğrudan uygulanabilir bir araç kutusu sunmaktadır. Türkiye'nin savunma ve havacılık sektörlerinde faaliyet gösteren kurumlar, burada geliştirilen yol haritasını dikkate

alarak kendi kurumsal stratejilerini şekillendirebilir ve iş birliği modellerini gözden geçirebilir.

Araştırmanın öne çıkan bir diğer boyutu, kullanılan katılımcı yöntemlerin yarattığı etkileşim kapasitesidir. Üçlü sarmal modeline dayalı olarak sanayi, kamu ve akademi aktörlerinin bir araya getirilmesi, öngörü sürecine yalnızca çok yönlü bir bakış açısı kazandırmamış; aynı zamanda geleceğe dair kolektif bir sahiplenme duygusu yaratmıştır. Bu yaklaşım, Türkiye'de sıklıkla eksikliği hissedilen "ortak vizyon üretme" kapasitesinin artırılmasına katkı sağlayabilecek niteliktedir. Katılımcılar tarafından üretilen öngörü ifadelerinin tümevarımsal biçimde kodlanarak temalara ayrılması, hem sahadan gelen seslerin doğrudan yansıtılmasına hem de bu seslerin sistematik bilgiye dönüştürülmesine imkân tanımıştır. Böylelikle, politika yapıcıların çoğu zaman ulaşmakta zorlandığı uzman bilgisi ile stratejik karar süreçleri arasında bir köprü kurulmuştur.

Tezde geliştirilen yol haritası, aynı zamanda esnek ve ölçeklenebilir yapısıyla dikkat çekmektedir. Kısa vadeli öneriler, acil boşlukların giderilmesi ve temel kapasitenin inşa edilmesine odaklanırken; orta vadeli öneriler bu kapasitenin kurumsallaştırılmasını ve sürdürülebilir iş birliklerine dönüştürülmesini hedeflemektedir. Uzun vadeli öneriler ise yalnızca teknik hedefler sunmakla kalmayıp, aynı zamanda çevresel sürdürülebilirlik ve küresel rekabet gücü boyutlarını da içermektedir. Böylece ortaya çıkan yol haritası, yalnızca lineer bir gelişim sürecini değil, birbirini tamamlayan ve güçlendiren aşamaların bütüncül bir entegrasyonunu temsil etmektedir. Bu yaklaşım, politika uygulamalarında süreklilik ve bütünlük sağlanması açısından kritik bir değer taşımaktadır.

Bununla birlikte, çalışma yalnızca teknik ve politik boyutlarla sınırlı kalmamış, aynı zamanda metodolojik anlamda da yenilikçi bir katkı sunmuştur. Gelecekler Çarkı ve Tersgörü yöntemlerinin ardışık biçimde kullanılması, hem keşifsel hem de normatif öngörü süreçlerinin birbirini tamamlayıcı biçimde işlemesini mümkün kılmıştır. Bu yöntemsel entegrasyon, literatürde sıklıkla vurgulanan ancak uygulamada nadiren karşılaşılan bir boşluğu doldurmakta; öngörü çalışmalarının daha etkin, izlenebilir ve politika üretimine uygun hale gelmesine imkân tanımaktadır. Ayrıca, süreç boyunca

kullanılan dijital platformların katılımcı deneyimini kolaylaştırması, yöntemlerin gelecekte daha geniş katılımlı öngörü çalışmalarında da rahatlıkla uygulanabileceğini göstermektedir.

Tezin ortaya çıkardığı önemli bulgulardan biri, balpeteği yapılı kompozitlerin yalnızca bir malzeme teknolojisi olarak değil, aynı zamanda daha geniş bir dönüşüm vizyonuyla ilişkilendirilebilecek bir potansiyel taşıdığıdır. Ultra hafiflik, yüksek dayanım, çevre dostu tasarım ve düşük maliyet gibi nitelikler, aslında savunma ve havacılık ekosisteminin gelecekteki yönelimlerini belirleyecek stratejik kriterlerin somut bir yansımasıdır. Dolayısıyla, bu malzemelerin gelişim süreçleri aynı zamanda Türkiye'nin teknolojik bağımsızlık hedefleri, sürdürülebilir kalkınma vizyonu ve uluslararası rekabet stratejileriyle doğrudan ilişkilidir. Bu bağlamda, tezde geliştirilen politika önerileri yalnızca teknik Ar-Ge projeleri için değil, aynı zamanda daha geniş stratejik planlama çerçeveleri için de yol gösterici niteliktedir.

Bulgular ayrıca, savunma ve havacılık sektörlerinde uzun vadeli planlamanın ne denli kritik olduğunu bir kez daha ortaya koymaktadır. Kısa vadeli çözümlerin ötesine geçemeyen yaklaşımlar, küresel rekabetin hızla değiştiği bir ortamda yetersiz kalmakta; teknoloji geliştirme süreçlerinin istikrarsız ve dağınık ilerlemesine yol açmaktadır. Tez kapsamında önerilen öngörü temelli yaklaşım, geleceğin belirsizliklerini sistematik biçimde yönetmeyi mümkün kılmakta; karar alıcıların daha sağlam, esnek ve vizyoner politikaların geliştirmesine olanak vermektedir. Bu yönüyle çalışma savunma planlaması, teknoloji yönetimi ve stratejik öngörü alanlarına da değerli katkılar sunmaktadır.

Elbette, ortaya konulan metodoloji ve politika önerilerinin hayata geçirilebilmesi, yalnızca teknik çalışmalarla sınırlı olmayıp, güçlü bir kurumsal irade ve koordinasyon mekanizmaları gerektirmektedir. Kamu, sanayi ve akademi aktörlerinin birbirini tamamlayan roller üstlenmesi; ortak fonlama, veri paylaşımı ve sertifikasyon süreçlerinde şeffaflık sağlaması; ulusal ve uluslararası standartlara uyum konusunda kararlılık göstermesi bu sürecin başarısı için kritik olacaktır. Türkiye'nin savunma ve havacılık vizyonunda balpeteği yapılı kompozitlerin stratejik bir rol üstlenebilmesi, ancak bu tür bütüncül ve koordineli adımların atılmasıyla mümkün olacaktır.

Sonuç olarak, bu tez yalnızca belirli bir malzeme teknolojisinin geleceğini incelemekle kalmamış; aynı zamanda öngörüye dayalı politika geliştirmenin nasıl uygulanabileceğine dair bir örnek ortaya koymuştur. Çalışmanın bulguları, karar alıcılar için uygulanabilir, akademi için yöntemsel, sanayi için ise stratejik bir referans noktası sunmaktadır. Daha da önemlisi, ortaya çıkan yöntemsel çerçevenin başka teknolojik alanlara da uyarlanabilecek esnekliğe sahip olması, tezin katkılarını balpeteği yapılı kompozitlerin ötesine taşımaktadır. Bu çerçevede, çalışma yalnızca bir vaka analizinden ibaret olmayıp, Türkiye'nin geleceğe dönük politika oluşturma kapasitesinin geliştirilmesine katkıda bulunan bir adım niteliğindedir.

G. THESIS PERMISSION FORM / TEZ İZİN FORMU

(Please fill out this form on computer. Double click on the boxes to fill them)

ENSTİTÜ / INSTITUTE

Fen Bilimleri Enstitüsü / Graduate School of Natural and Applied Sciences ☐

Sosyal Bilimler Enstitüsü / Graduate School of Social Sciences ☒

Uygulamalı Matematik Enstitüsü / Graduate School of Applied Mathematics ☐

Enformatik Enstitüsü / Graduate School of Informatics ☐

Deniz Bilimleri Enstitüsü / Graduate School of Marine Sciences ☐

YAZARIN / AUTHOR

Soyadı / Surname : KOCAMIŞ
Adı / Name : Gül Beyza
Bölümü / Department : Bilim ve Teknoloji Politikası Çalışmaları / Science and Technology Policy Studies

TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English): FORESIGHT-BASED POLICY DEVELOPMENT IN THE DEFENSE AND AEROSPACE INDUSTRY: THE CASE OF HONEYCOMB MATERIAL TECHNOLOGY

TEZİN TÜRÜ / DEGREE: **Yüksek Lisans** / Master ☒ **Doktora** / PhD ☐

1. **Tezin tamamı dünya çapında erişime açılacaktır. /** Release the entire work immediately for access worldwide. ☒
2. **Tez iki yıl süreyle erişime kapalı olacaktır.** / Secure the entire work for patent and/or proprietary purposes for a period of **two years. *** ☐
3. **Tez altı ay süreyle erişime kapalı olacaktır.** / Secure the entire work for period of **six months**. ***** ☐

***** *Enstitü Yönetim Kurulu kararının basılı kopyası tezle birlikte kütüphaneye teslim edilecektir. / A copy of the decision of the Institute Administrative Committee will be delivered to the library together with the printed thesis.*

Yazarın imzası / Signature ..... **Tarih** / Date .....
(Kütüphaneye teslim ettiğiniz tarih. Elle doldurulacaktır.)
(Library submission date. Please fill out by hand.)

Tezin son sayfasıdır. / This is the last page of the thesis/dissertation.