

THE EFFECT OF TECHNOLOGY CONVERGENCE ON
CROSS-SECTORAL CO-EVOLUTION:
THE CASE OF AUTOMOTIVE & ICT SECTORS

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

BY

DUYGU SARAÇOĞLU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
SCIENCE AND TECHNOLOGY POLICY STUDIES

JULY 2021

Approval of the thesis:

**THE EFFECT OF TECHNOLOGY CONVERGENCE ON
CROSS-SECTORAL CO-EVOLUTION:
THE CASE OF AUTOMOTIVE & ICT SECTORS**

submitted by **DUYGU SARAÇOĞLU** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Science and Technology Policy Studies**, the **Graduate School of Social Sciences of Middle East Technical University** by,

Prof. Dr. Yaşar KONDAKÇI
Dean
Graduate School of Social Sciences

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

Assoc. Prof. Dr. İ. Semih AKÇOMAK
Supervisor
Department of Science and Technology Policy Studies

Examining Committee Members:

Assoc. Prof. Dr. M. Yılmaz ÜSTÜNER (Head of the Examining Committee)
Middle East Technical University
Department of Political Science and Public Administration

Assoc. Prof. Dr. İ. Semih AKÇOMAK (Supervisor)
Middle East Technical University
Department of Science and Technology Policy Studies

Prof. Dr. Erkan ERDİL
Middle East Technical University
Department of Economics

Assist. Prof. Dr. Güleda DOĞAN
Hacettepe University
Department of Information Management

Assist. Prof. Dr. Serkan BÜRKEN
Ostim Technical University
Department of Mechatronics



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: Duygu SARAÇOĞLU

Signature:

ABSTRACT

THE EFFECT OF TECHNOLOGY CONVERGENCE ON CROSS-SECTORAL CO-EVOLUTION: THE CASE OF AUTOMOTIVE & ICT SECTORS

SARAÇOĞLU, Duygu

Ph.D., Science and Technology Policy Studies

Supervisor: Assoc. Prof. Dr. İ. Semih AKÇOMAK

July 2021, 322 pages

Recent developments show that convergence, particularly technology convergence, is one of the main trends that shape the new economy. Such that, the dominant sector is being created by more than one converging sector that, in turn, provides the infrastructure for wealth and innovation creation by all sectors. Thus, convergence is becoming the basis of all sectors and it reduces the threshold of transforming the economy. Moreover, recent studies suggest that key enabling technologies (KETs) that have disruptive impact on sectoral transformation and blurring of boundaries of distinctive sectors, emerge based on technology convergence. As a result, the dynamics of the respective innovation systems (IS) also transform in a co-evolutionary perspective. Thus far, the IS approach has concerned with the dynamics of only one dominant sector and co-evolution within the sector, while only paying attention to the links of related/supportive sectors. Therefore, there is room for improvement to explain the effect of technology convergence over cross-sectoral dynamics and respective IS, as well as examining the impacts of KETs over sectoral transformation.

For these reasons, this thesis aims to contribute theoretically and methodologically to the field of IS by conceptualizing an understanding of cross-sectoral co-evolution. Empirically, further refinement of the conceptualization based on a comparative multi-criteria assessment of more than one sector is applied for automotive and information and communication technology sectors. As a result, a cross-sectoral matching analysis method is proposed and a Cross-Sectoral Innovation System approach is conceptualized as a contribution to the IS literature.

Keywords: Technology Convergence, Cross-Sectoral Co-Evolution, Innovation Systems, Automotive Sector, ICT Sector

ÖZ

TEKNOLOJİ YAKINSAMASININ SEKTÖRLER ARASI BİRLİKTE EVİRİMLEŞMEYE ETKİSİ: OTOMOTİV VE BİLGİ VE İLETİŞİM TEKNOLOJİLERİ SEKTÖRLERİ DURUM ÇALIŞMASI

Saraçoğlu, Duygu

Doktora, Bilim ve Teknoloji Politikaları Çalışmaları Bölümü

Tez Yöneticisi: Doç. Dr. İ. Semih Akçomak

Temmuz 2021, 322 sayfa

Son gelişmeler yakınsamanın, özellikle teknoloji yakınsamasının, yeni ekonomiyi oluşturan temel yönelimlerden biri olduğunu göstermektedir. Öyle ki, baskın sektör bir ya da birden fazla birbirine yakınsayan sektörden meydana gelmekte, böylece ekonomik refah ve yeniliğin altyapısını oluşturmaktadır. Dolayısıyla, yakınsama tüm sektörlerin temeli haline gelmekte ve sektörlerin dönüşümünde eşiği her gün düşürmektedir. Diğer taraftan, güncel çalışmalar kilit etkinleştirici teknolojilerin en çok teknoloji yakınsamasından etkilenecek oluştuğunu ve sektörlerin birlikte evrimleşerek dönüşümüne önemli oranda etkisi olduğunu ortaya koymaktadır. Mevcut yenilik sistemleri yaklaşımları sadece bir baskın sektörün dinamikleri ve bu dinamiklerin birlikte evrimleşmesine odaklanmakta olup baskın sektörün ilgili ya da destekleyici sektörlerle bağlantılarını incelemektedir. Dolayısıyla mevcut yenilik sistemleri yaklaşımlarının, teknoloji yakınsamasının sektörler arası dinamikleri açıklamak ve kilit etkinleştirici teknolojilerin sektörlerin dönüşümüne etkisini incelemek açısından iyileştirmeye açık olduğu düşünülmektedir. Buradan hareketle,

bu tez ile yenilik sistemleri yaklaşımları çerçevesinde teknoloji yakınsaması tabanlı sektörler arası birlikte evrimleşme kavramına odaklanılmaktadır. Kavramsallaştırma çalışmasının daha da sağlamlaştırılması amacıyla birden fazla sektör için çoklu kriterli karşılaştırma analizi otomotiv ve bilgi ve iletişim sektörlerine uygulanmıştır. Sonuç olarak, yenilik sistemleri literatürüne bir katkı olarak teknoloji yakınsamasından doğan sektörler arası birlikte evrimleşme kavramı için sektörler arası eşleme analiz yöntemi önerilmiş ve Sektörler Arası Yenilik Sistemi yaklaşımı sunulmuştur.

Anahtar Sözcükler: Teknoloji Yakınsaması, Sektörler Arası Birlikte Evrimleşme, Yenilik Sistemleri, Otomotiv Sektörü, Bilgi ve İletişim Teknolojileri Sektörü



To my dear family.

ACKNOWLEDGMENTS

First, I would like to express grateful acknowledgment for the continuous and valuable understanding, suggestions, and contributions given by my thesis supervisor Assoc. Prof. Dr. İ. Semih Akçomak.

I would also like to express my gratitude to Prof. Dr. Erkan Erdil and Assoc. Prof. Dr. Mustafa Yılmaz Üstüner for their continuous and valuable guidance during the thesis monitoring and examining process.

Likewise, I would like to express my gratitude to Prof. Dr. Franco Malerba for the encouragement of pursuing my doctorate in this challenging subject.

I would also like to express my sincerest thanks to Dr. Zeynep Taşkın and Assist. Prof. Dr. Güleda Doğan for their precious suggestions regarding the improvement of bibliometric analysis. I am also grateful to Assist. Prof. Dr. Serkan Bürken for his valuable contribution.

Finally, I would like to thank myself for not giving up no matter what, and my family and my friends, providing me with uninterrupted support in completing this stressful and difficult process.

Ankara, 2021
Duygu Saraçoğlu

TABLE OF CONTENTS

PLAGIARISM	iii
ABSTRACT	iv
ÖZ.....	vi
DEDICATION	viii
ACKNOWLEDGMENTS.....	ix
TABLE OF CONTENTS	x
LIST OF TABLES	xiv
LIST OF FIGURES.....	xv
LIST OF ABBREVIATIONS	xviii
CHAPTERS	
1. INTRODUCTION.....	1
1.1. Statement of the Problem	3
1.2. Purpose of the Study	5
1.3. Research Questions	5
1.4. The Methodology and the Organization of the Dissertation	6
1.4.1. Details of the Steps and the Organization of the Dissertation.....	9
1.5. Scope of the Dissertation.....	16
1.6. Researcher's Motivation and Significance of the Study	19
2. THEORETICAL BACKGROUND	22
2.1. Technology Convergence.....	29
2.1.1. Technology Convergence in NIS Approach	33
2.1.2. Technology Convergence in RIS Approach.....	34
2.1.3. Technology Convergence in SIS Approach.....	34
2.1.4. Technology Convergence in CIS Approach.....	42

2.2. Cross-Sectoral Co-Evolution.....	43
2.2.1. Cross-Sectoral Co-Evolution in NIS Approach.....	47
2.2.2. Cross-Sectoral Co-Evolution in SIS Approach.....	48
2.3. Industry Convergence.....	50
2.4. Demand-Side Innovation Policies, IS Approaches and Convergence.....	58
2.5. Key Findings of the Literature Review.....	65
3. DESCRIPTIVE STUDY OF CROSS-SECTORAL DYNAMICS.....	67
3.1. Descriptive Research of Cross-Sectoral Dynamics.....	69
3.1.1. Descriptive Research Outputs.....	75
3.2. Cross-Sectoral Matching Analysis of Sectoral Dynamics Separately.....	84
3.3. Key Findings of the Descriptive Study of Cross-Sectoral Dynamics.....	86
4. PROPOSING AN ANALYSIS METHOD FOR CROSS-SECTORAL DYNAMICS.....	87
4.1. Steps for the Design of the Analysis Method.....	87
4.2. Context of the Analysis Method.....	88
4.3. Narrowing the Context and the Analysis Method for CSIS Approach.....	92
4.4. Determination of Dimensions and Indicators Quantitative and Qualitative Analysis Methods.....	95
4.5. Selection of Sectors for the Case Study for CSIS Approach.....	100
4.5.1. Scope of the Selected Sectors.....	101
4.6. Determination of TAs and Keywords for the Case Study.....	103
5. CASE STUDY: CROSS-SECTORAL INNOVATION SYSTEM ANALYSIS FOR AUTOMOTIVE & ICT SECTORS.....	105
5.1. Quantitative Analysis.....	106
5.1.1. Quantitative Analysis for Science Convergence.....	106
5.1.1.1. Scope and Method.....	106
5.1.1.2. Analysis Results and Evaluation.....	112
5.1.2. Quantitative Analysis for Technology Convergence.....	131
5.1.2.1. Scope and Method.....	131
5.1.2.2. Analysis Results and Evaluation.....	135

5.1.3. Quantitative Analysis for Market Convergence.....	146
5.1.3.1. Scope and Method.....	146
5.1.3.2. Analysis Results and Evaluation.....	147
5.1.3.3. Cross-Sectoral Matching Analysis Based On Global Market Trends.....	157
5.1.3.4. Cross-Sectoral Matching Analysis Based On Trends of Determined Countries	168
5.1.3.5. Cross-Sectoral Matching Analysis Based On Trends of Determined Companies	182
5.2. Qualitative Analysis	201
5.2.1. Expert Review	201
5.2.1.1. Scope and Method.....	201
5.2.1.2. Analysis Results and Evaluation	204
5.3. Further Remarks of the Case Study for the Concept of CSIS Approach	208
6. CONCEPTUALIZATION OF CROSS-SECTORAL INNOVATION SYSTEMS	213
7. CONCLUSION	222
7.1. Key Findings of The Thesis and The Concept of CSIS Approach	223
7.2. Key Policy Implications	229
7.2.1. Policy Implication 1: Development of Collaborative Innovation Mechanisms for Cross-Sectoral Approaches	229
7.2.2. Policy Implication 2: Support for Multi-, Cross- and Interdisciplinary Areas, R&D and Test Infrastructures	231
7.2.3. Policy Implication 3: Need for Proactive Cross-Sectoral Regulations and Standardization Process.....	233
7.3. Future Studies and Further Remarks	234
REFERENCES.....	239
APPENDICES	
A. SCOPE OF SUB-TECHNOLOGY AREAS AND KEYWORD CLUSTERS FOR AUTOMOTIVE AND ICT SECTORS.....	266

B. CODING SAMPLES FOR BIBLIOMETRIC ANALYSES	269
C. ASSIGNEES PER EACH SUB TECHNOLOGY AREA IN BIBLIOMETRIC ANALYSIS BASED ON PATENTS	272
D. GLOBAL INDEXES IN DETERMINATION OF EXAMINED COUNTRIES AND COMPANIES	274
E. DATA FOR TURKEY REGARDING QUANTITATIVE ANALYSIS	280
E.1. Data for Turkey for Quantitative Analysis of Science Convergence Regarding ICT-Based AUTO Sector	280
E.2. Data for Turkey for Quantitative Analysis of Science Convergence Regarding AUTO-Based ICT Sector	281
E.3. Data for Turkey for Quantitative Analysis of Market Convergence	282
F. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE .	288
G. CURRICULUM VITAE	289
H. TURKISH SUMMARY/TÜRKÇE ÖZET	292
I. THESIS PERMISSION FORM / TEZ İZİN FORMU	322

LIST OF TABLES

Table 2.1. Comparison of Current IS Approaches and CSIS Approach	55
Table 4.1. Methods for Mapping Innovation Systems	92
Table 4.2. Methodologies for Measuring Convergence	94
Table 4.3. Summary of Dimensions and Indicators of the Cross-Sectoral Matching Analysis Method	99
Table 4.4. Scope of Automotive Sector, NACE Rev.2	101
Table 4.5. Scope of ICTs Sector, NACE Rev.2	102
Table 4.6. Sub-Technology Areas for Automotive and ICT Sectors	104
Table 5.1. Summary of Cross-Sectoral Approaches for Examined Countries	155
Table 5.2. Summary of Cross-Sectoral Approaches for Examined Companies	156
Table A.1. Automotive Sub-Technology Areas and Scopes	266
Table A.2. ICT Sub-Technology Areas and Scopes	266
Table B.1. Coding Sample for AUTO + Information Security Keyword Cluster for Scientific Publication Data Retrieval from SCOPUS Database	269
Table B.2. Coding Sample for AUTO + Information Security Keyword Cluster for Patent Data Retrieval from Derwent Database	271
Table D.1. GII and GCI, 2017-2018 Comparison, Top 25	277
Table D.2. The Global Innovation 1000 Study, Top 25	278
Table D.3. The Global Innovation 1000 Study, Filtered by Automotive and ICT ..	279

LIST OF FIGURES

Figure 1.1. Brief Sketch of the Implemented Methodology	8
Figure 2.1. The Terminology of Convergence (Kim et al., 2015, p.1737, Edited)....	32
Figure 2.2. Current SIS approach versus CSIS Approach	42
Figure 2.3. The Concept of Industry 4.0 (Burrus, 2013)	46
Figure 2.4. Visualization of Industry Convergence (Hacklin, 2008; Kim et al., 2015, p. 1735, Edited).....	52
Figure 3.1. Examples of Converging Industries and Related KETs	69
Figure 3.2. Co-occurrence Mapping of Descriptive Research, 2007-2017.....	72
Figure 3.3. Overlay Visualization for Co-occurrence Mapping of Descriptive Research, 2007-2017.....	73
Figure 3.4. Overlay Visualization of Co-Authorship Mapping of Countries from Descriptive Research, 2007-2017	74
Figure 3.5. Result of the Cross-Sectoral Matching Analysis Taking Automotive and ICT Sectors Separately	86
Figure 4.1. Design of the Analysis Method for CSIS Approach	91
Figure 4.2. Proposed Analysis Method for the Case Study Regarding CSIS Approach.....	98
Figure 5.1. The Logic of Cross-Sectoral Matching Analysis Method for Science Convergence Based On Matching TAs & Keyword Clusters of Automotive & ICT	109
Figure 5.2. Frequency of ICT-Based AUTO TAs, Publication Counts, 2007-2017	113
Figure 5.3. Frequency of ICT-Based AUTO TAs, Citation Counts, 2007-2017.....	113
Figure 5.4. ICT-Based AUTO, Network Visualization of Co-occurrence Mapping	116
Figure 5.5. ICT-Based AUTO, Timeline-Based Overlay Visualization of Co-occurrence Mapping, 2007-2017	117

Figure 5.6. ICT-Based AUTO, Overlay Visualization of Co-occurrence Mapping with Avg. Citations, 2007-2017	118
Figure 5.7. ICT-Based AUTO, Countries for Cross-Sectoral Analysis	120
Figure 5.8. Frequency of AUTO-Based ICT TAs, Publication Counts, 2007-2017	122
Figure 5.9. Frequency of AUTO-Based ICT TAs, Citation Counts, 2007-2017	122
Figure 5.10. AUTO-Based ICT, Network Visualization of Co-occurrence Mapping	126
Figure 5.11. AUTO-Based ICT, Timeline-Based Overlay Visualization of Co-occurrence Mapping, 2007-2017.....	127
Figure 5.12. AUTO-Based ICT, Overlay Visualization of Co-occurrence Mapping with Avg. Citations, 2007-2017.....	128
Figure 5.13. AUTO-Based ICT, Countries for Cross-Sectoral Analysis	129
Figure 5.14. AUTO-ICT Sector, Frequency of TAs Based On Patents, 2007-2017	136
Figure 5.15. AUTO-ICT Sector, Countries for Cross-Sectoral Analysis Based On Patents	139
Figure 5.16. AUTO-ICT Sector, Top 5 Assignees for the Most Prominent TAs for Cross-Sectoral Analysis Based On Patents	139
Figure 5.17. AUTO-ICT Sector, Top 5 Assignees for the Most Prominent TAs for Cross-Sectoral Analysis Based On Backward Citations for Patents	140
Figure 5.18. AUTO-ICT Sector, Network Visualization of Co-occurrence Mapping of Patents.....	143
Figure 5.19. AUTO-ICT Sector, Timeline-Based Overlay Visualization of Co-occurrence Mapping, 2007-2017.....	144
Figure 5.20. AUTO-ICT Sector, Overlay Visualization of Co-occurrence Mapping with Avg. Citations, 2007-2017.....	145
Figure 5.21. Level of Focus and Determined KETs in Cross-Sectoral Perspective for Examined Countries	152
Figure 5.22. AUTO-ICT Cross-Sectoral Convergence (DETECON, 2011).....	158
Figure 5.23. Four KETs and Current and Future Enablers in the Automotive Sector (McKinsey&Company, 2016).....	161

Figure 5.24. Roadmap for Automotive Technology Advancement: Intelligent Mobility (CAR Group, 2017).....	165
Figure 5.25. JASPAR Members List as of Sep 2017 (JASPAR, 2019).....	175
Figure 5.26. UK Automotive Sector Priorities 2017-2022 (SMMT, 2017).....	177
Figure 5.27. Comparison of Apple and Tesla for Vertical Integration (ARK Investment Management LLC, 2018)	199
Figure 5.28. Summary of the Expert Contribution Form.....	203
Figure 5.29. Distribution of Contributors of the Expert Review	205
Figure 5.30. Sankey Diagram for Prioritization of TAs for ICT-Based AUTO Sector and AUTO-Based AUTO Sector	206
Figure 5.31. Keyword Cloud for Delphi Statements.....	207
Figure 5.32. The Most Impactful Convergence Type for Cross-Sectoral Co-Evolution.....	208
Figure 5.33. Sankey Diagram for TAs Based On Normalization of Total Analysis Scores.....	210
Figure 5.34. Sankey Diagram for Emerging KETs Based On Normalization of Total Analysis Scores	211
Figure 5.35. Sankey Diagram for Relatedness of Automotive and ICT TAs.....	212
Figure 6.1. Comparison of Features of SIS and CSIS Approaches	219
Figure 6.2. Conceptualization of CSIS Approach.....	221
Figure C.1. AUTO-ICT Sector, Top 5 Assignees for Each TA Based On Patents..	272
Figure C.2. AUTO-ICT Sector, Top 5 Assignees for Each TA Based On Backward Citations of Patents	273
Figure E.1. ICT-Based AUTO, Frequency of ICT TAs for Turkey Based On Total Publication Counts, 2007-2017	281
Figure E.2. AUTO-Based ICT, Frequency of AUTO TAs for Turkey Based On Total Publication Counts, 2007-2017	282

LIST OF ABBREVIATIONS

3G/4G/5G/6G	3rd/4th/5th/6th Generation Technology Standard for Broadband Cellular Networks
ADAS/AD	Advanced Driver Assistance Systems/Autonomous Driving
AGVs	Autonomous Guided Vehicles
AI	Artificial Intelligence
AUTO	Automotive
AUTOSAR	AUTomotive Open System ARchitecture
BEV	Battery Electric Vehicle
BİT	Information and Communication Technologies (Bilgi ve İletişim Teknolojileri)
BMWi	The Federal Ministry for Economic Affairs and Energy of Germany
C-V2X	Cellular Vehicle-to-Everything Communication
CAD	Computer Aided Design
CAGR	Compound Annual Growth Rate
CAN	Controller Area Network
CATA	Canadian Advanced Technology Collaboration
CAV(s)	Connected and Autonomous Vehicle(s)
CFRP	Carbon-Fiber-Reinforced Polymers/Plastics
CIS	Complex Innovation System(s)
CMOs	Chief Marketing Officers
Comp.	Company
CoolMOS	A Technology For High Voltage Power MOSFETs
Corp.	Corporation
CPs	Cyber-Physical Systems
CPU	Central Processing Unit
CSIS	Cross-Sectoral Innovation System

DoSTIP	TÜBİTAK Department of Science, Technology and Innovation Policies (TÜBİTAK Bilimi Teknoloji ve Yenilik Politikaları Daire Başkanlığı)
DSP	Digital Signal Processor
DSRC	Dedicated Short-Range Communication
DWPI	Derwent World Patent Index
EAST-ADL	An Architecture Description Language for Automotive Embedded Systems
EV(s)	Electric Vehicle(s)
EHV(s)	Electric and Hybrid Vehicle(s)
EPO	European Patent Office
ESPs	Engineering Service Providers
FC	Fuel Cell
FCA	Fiat Chrysler Automobiles
FPGA	Field-Programmable Gate Array
G2V	Grid-to-Vehicle Communication
GCI	Global Competitiveness Index
GII	Global Innovation Index
GIS	Geographic Information Systems
GM	General Motors Company
GPS	Global Positioning System
GPU	Graphics Processing Unit
HEV(s)	Hybrid Electric Vehicle(s)
IC(s)	Integrated Circuit(s)
ICT(s)	Information and Communication Technologies
Inc.	Incorporation
IoT	Internet of Things
IP	Internet Protocol/ Intellectual Property
IPC	International Patent Classification
IPT	Inductive Power Transfer

IPv6	Internet Protocol version 6 (the most recent version of the Internet Protocol)
IS	Innovation System(s)
ISIC	United Nations' International Standard Industrial Classification of All Economic Activities
ITRI	Industrial Technology Research Institute
JPO	Japan Patent Office
JRC-IPTS	European Commission's Joint Research Centre - Institute for Prospective Technological Studies
KETs	Key Enabling Technologies
Li-On	Lithium-Ion
LiDAR	Light Detection and Ranging
LSA	Latent Semantic Analysis
Ltd.	Limited
M2M	Machine-to-Machine Communication
METU	Middle East Technical University (Orta Doğu Teknik Üniversitesi)
MGI	McKinsey Global Institute
ML	Machine Learning
MOSFET(s)	Metal–Oxide–Semiconductor Field-Effect Transistor(s)
NACE	The Statistical Classification of Economic Activities in the European Community
NBT	Nano- and Biotechnology
NIS	National Innovation System(s)
NoAE	The German Automobile Excellence Network
NVA	Networked Vehicle Association
OECD	Organization of Economic Cooperation and Development
OEM	Original Equipment Manufacturer
OTEP	Automotive Technology Platform of Turkey (Otomotiv Teknoloji Platformu)

PEMFC	Proton Exchange Membrane Fuel Cell
PFC	Power Factor Correction
PHEV	Plug-in Hybrid Electric Vehicle
R&D	Research and Development
RDI	Research, Development and Innovation
RIS	Regional Innovation System(s)
S&T	Science and Technology
SiC	Silicon-Carbide
SIC	Standard Industrial Classification
SIS	Sectoral Innovation System(s)
S.Korea	South Korea
SOC	State of Charge
STIPC	Science, Technology and Innovation Policies Council Under The Turkish Presidency (T.C. Cumhurbaşkanlığı Bilim, Teknoloji ve Yenilik Politikaları Kurulu)
Sys	System(s)
TA(s)	Sub-Technology Area(s)
TIS	Technological Innovation System(s)
TOBB	The Union of Chambers and Commodity Exchanges of Turkey (Türkiye Odalar ve Borsalar Birliği)
TOGG	Turkey's Automobile Initiative Group (Türkiye'nin Otomobili Girişim Grubu)
TÜBİTAK	Scientific and Technological Research Council of Turkey (Türkiye Bilimsel ve Teknolojik Araştırma Kurumu)
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
ULEVs	Ultra-Low Emission Vehicles
US/USA	United States/United States of America
USPTO	United States Patent and Trademark Office
V2G	Vehicle-to-Grid Communication

V2I	Vehicle-to-Infrastructure Communication
V2V	Vehicle-to-Vehicle Communication
V2X	Vehicle-to-Everything Communication (including vulnerable road users, such as cyclists and pedestrians)
VANET(s)	Vehicular Ad-Hoc Network(s)
WEF	World Economic Forum
WIPO	World Intellectual Property Organization
Zigbee	IEEE 802.15.4-Based Worldwide Standard for Low Power Mesh Networks
ZVS	Zero-Voltage Switching

CHAPTER 1

INTRODUCTION

Technological developments play a crucial role in powering growth and transforming economies. As Joseph Schumpeter observed that significant advances in economies are often accompanied by a process of “creative destruction”, which is often driven by technological innovation and has a role in transforming sectoral structures. Recent developments show that convergence is one of the dominant trends that shape the new economy; especially technology convergence comes forward. In the new economy, the dominant economic sector is being created by one, or more than one converging sector that, in turn, provides the infrastructure for wealth creation by all sectors. Thus, convergence is becoming the basis of all sectors and is decreasing the threshold of the transformation of the economy and sectors. Convergence changes the way people do business, work, play, live, and probably even think as behavioral design developments show. All analyses of recent global trends emphasize the disruptive impact of convergence over sectors and put redefinition of sectors in focus as one of the major megatrends. Even though technological disruption is not new, currently value creation at the intersection of sectors generates convergence even more than yesterday and it accelerates its speed. As a result, once observed as hard and high sectoral boundaries are disappearing (Harvard Business Review, 2012; MGI, 2013; Gartner, 2014; KPMG, 2014; IBM, 2016; OECD Internet Economy Outlook, 2012, 2017a respectively, OECD STI Outlook 2016, 2018 respectively; Ernst & Young Global Megatrends, 2016, 2018, 2020 respectively; NATO, 2020).

One of the obvious examples of the aforementioned phenomenon is the accelerating digital transformation that affects every sector. By the use of ICTs in every field from daily life to the most critical fields - such as defense, automotive, health sectors - brings

out crucial changes in the sectoral dynamics. An example of the digital transformation can be given as the new media sector. The new media sector is the convergence of many other sectors such as traditional media but also mostly convergence of digital technologies, such as the telecommunications sector, mobile technologies, and consumer electronics. Another example can be given as the development and application of advanced and smart materials; which is interrelated with the converging technologies (nano-, bio-, genetics, etc.). So much so, sectors themselves are being redefined as converging technologies blur the barriers and attract companies from distinct sectors together to develop innovative solutions, especially against global and societal challenges. Recently, convergence is also observed drastically in different dynamics, such as science (knowledge) and market sides, which also leads to convergence of very different sectors with different bases, actors, markets, organizational structures, etc. In addition, while this transformation is happening it is observed as mutually exclusive, it is not just co-evolutionary for the actors of just one sector, but there is a cross-sectoral co-evolution.

Aside from digital transformation, traditional sectors such as agriculture and food are also having different transformations due to convergence effects, which can be scientific as well as market-driven. As a result, different sectors, so-called agri-food or bio-digital, emerge with different dynamics, which also brings different systemic approaches as a new sector. Another example can be functional foods, which is the convergence of the food sector and life sciences sector, as well as the cosmetics sector.

Furthermore, one of the crucial outputs of technology convergence is the formulation of key enabling technologies (KETs). MGI's (2013) study suggests that the combined potential economic impact by 2025 from the applications of the twelve KETs size tens of trillions of dollars per year. Twelve KETs are suggested as; mobile internet, automation, internet of things (IoT), cloud technology, advanced robotics, autonomous and near-autonomous vehicles, next-generation genomics, energy storage, 3D printing, advanced materials, advanced oil and gas exploration, and renewable energy.

Moreover, each KET is stated as disruptive for sectoral transformation. The impact of KETs is causing the formation of brand new sectors as well, which is also triggering the development of cross-sectoral approaches.

Most recently, NATO Science & Technology Trends 2020-2040 document suggests that emerging, disruptive and convergent technologies will be defining the socio-economic, scientific, and technologic landscape over the next twenty years. The common characteristics of these technologies also them being intelligent, interconnected, distributed, and digital. The synergistic combination and convergence of such technologies, for example, data-AI-autonomy-biotechnology-nanotechnology-materials-communication technologies-battery technologies, data-space-quantum-genetics-bio-manufacturing, space-hypersonics-materials, have the potential to generate disruptive effects beyond 2040 (NATO, 2020, pp.23-26). Achieving the full potential of irresistible technology convergence and KETs, while addressing their challenges, and their effects on economies and sectoral structures, require proactive policy making and widen current systemic approaches and methodologies to analyze the cross-sectoral dynamics.

1.1. Statement of the Problem

In recent years, there has been a drastic increase in research for analyzing system approach to study innovation. The innovation system (IS) approaches, whether national, regional, sectoral, or technological, have been widely used to map and explain interactions between various actors and dynamics. As regards to aforementioned examples, however, there is a gap in the literature to understand the case of convergence of two or more sectors. In addition to the process of the convergence and formation of a brand new sector that consists of dynamics of composing sectors, in the newly formed IS. There is also no method for analyzing the process of transformation of sectors due to the convergence effect or dynamics of such innovation systems.

In the IS literature (Malerba, 2004, 2009; Bergek et. al, 2008), it is often argued that the sectoral dynamics require a more systematic approach to analyze, while it is also debated that the approaches are inadequate. Some of the argued inadequacies of the IS approaches given as:

- (1) Focusing on the co-evolution between institutional innovation and technological innovation, as well as interdependent actors/new dynamics.
- (2) Identifying the interdependent relationships between different innovation system approaches.
- (3) Taking more quantitative models to simulate the dynamic systems of innovation.

Looking more closely at the work on sectoral innovation system (SIS) approach, it is concerning dynamics of one dominant sector; which are firms, other actors than firms, networks, demand, institutions, knowledge-base and knowledge creation, the basic proposes of interaction, variety generation, selection and co-evolution of these dynamics within the sector. Thus, it pays a lot of attention to exchange and co-opetition in a co-evolutionary perspective. While, SIS approach also pays attention to the links and interdependencies of related and/or supportive sectors (Malerba 2002a, 2004), it lacks in focus to explain the effect of technology convergence over cross-sectoral dynamics. On the other hand, recent developments in convergence literature include the transformation of sectors, however, it does not cover IS approaches.

Therefore, studying convergence and IS literature together is a brand new study area. In other words, there are no studies in both convergence literature and innovation systems literature that compare approaches by treating technology convergence and its effect on cross-sectoral co-evolution as the central theme. This is one of the theoretical novelties and contributions of the thesis to the existing realm of knowledge.

1.2. Purpose of the Study

The major aim of this thesis is to integrate ongoing systems of innovation studies and to provide a better understanding of the cross-sectoral point of view regarding the technology convergence trend and to understand if there is a co-evolution between sectors while developing a methodology to analyze and conceptualize cross-sectoral innovation system (CSIS) approach. More precisely, the research question of if there is a cross-sectoral co-evolution process based on technology convergence is determined by focusing on the analysis of technology convergence, (cross-sectoral) co-evolution, and industry convergence from the perspective of IS literature.

For this matter, the gaps in the current innovation system literature to determine the effects of technology convergence over co-evolution of more than one dominant sector are examined and the view of CSIS approach is determined (Table 2.1, Chapter 2). A methodology that consists of both quantitative and qualitative analysis methods, is developed and conducted to analyze and observe the effect of convergence (especially technology convergence) on cross-sectoral transformation and co-evolutionary aspects.

While developing the methodology and CSIS approach the advantages of understanding the dynamics that are related to the formation of KETs based on the conceptualization of the cross-sectoral co-evolution are also considered.

1.3. Research Questions

Answers to the following main research question are given in the study:

- (1) In the perspective of innovation systems approaches, is there a cross-sectoral co-evolution process based on technology convergence?

Furthermore, there are two auxiliary research questions of the study:

- (2) What are the gaps in the current innovation system literature to determine the effects of technology convergence over co-evolution of more than one dominant sector?
- (3) What are the advantages of understanding the dynamics that are related to the formation of “Key Enabling Technologies (KETs)” based on the conceptualization of the cross-sectoral co-evolution?

1.4. The Methodology and the Organization of the Dissertation

As given with the research questions, the main aim of this thesis is to investigate the relation between technology convergence and cross-sectoral co-evolution from the perspective of innovation system approaches. For that matter, firstly it is also aimed to understand the gaps in the current innovation system literature to determine a better methodology to understand how an innovation system (IS) works when there is more than one dominant sector based on the effect of convergence, especially technology convergence. In addition, this thesis covers an understanding of “Key Enabling Technologies (KETs)” which are considered as one of the main triggers for cross-sectoral co-evolution. KETs are also important elements for the co-evolutionary aspects of the formation of new dominant sectors involving more than one dominant sector.

The next chapter reviews the body of literature related to this study and presents a comparative analysis of IS literature for understanding the aspect of technology convergence, cross-sectoral co-evolution, and industry convergence.

As a result of the literature review there are three main findings:

- (1) Current IS approaches focus on the dynamics of only one dominant sector and co-evolution within its own dynamics.

- (2) Pays attention to the links and interdependencies of related/supportive sectors.
- (3) Remains inadequate to explain cross-sectoral dynamics based on the impact of technology convergence.

Moreover, demand-side innovation policies literature is reviewed to present the relation between the technology-push and market-pull effects as in push-pull dynamic between technology convergence towards market convergence and the formation of industry convergence, and KETs.

To summarize, the main finding of the literature review is that there are no adequate methodologic studies regarding technology convergence, cross-sectoral co-evolution, and industry convergence in the IS literature to examine the formation of new sectors with new dynamics. Convergence triggers systemic transformations and has a policy significance. However, the IS literature and convergence literature are disintegrated in examining the systemic transformations because of the lack of comprehensive frameworks nor methods that focuses on more than one dominant sector.

A brief sketch of the implemented methodology of this thesis is given in Figure 1.1 that includes seven main steps. Consequently, further explanations are given in more detail by each step.

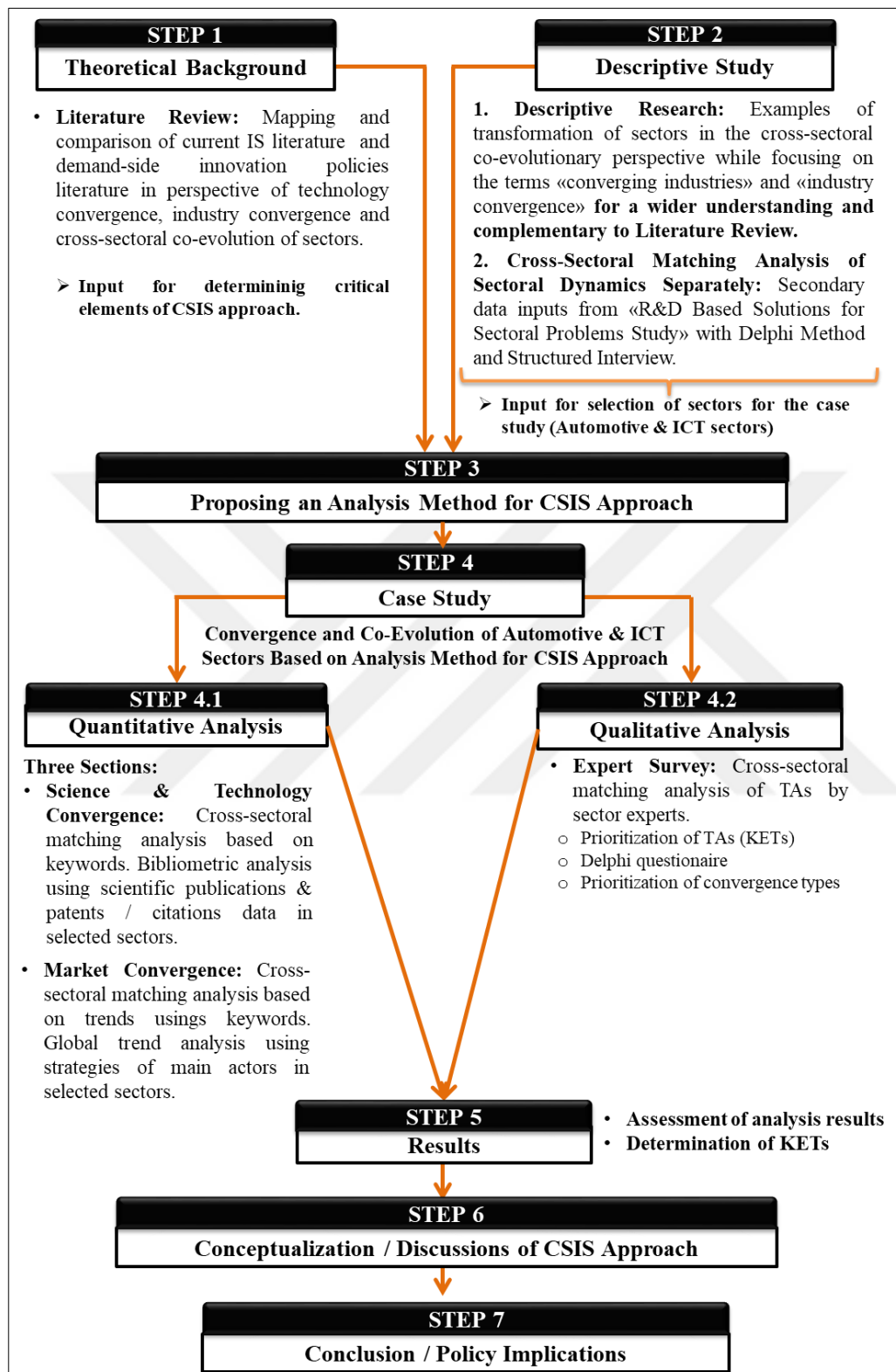


Figure 1.1. Brief Sketch of the Implemented Methodology

1.4.1. Details of the Steps and the Organization of the Dissertation

Step 1 is “Theoretical Background”. For this step, literature related to IS in the perspective of technology convergence and cross-sectoral co-evolution is reviewed. In compliance with the maturity level achieved in the notion of IS literature (National Innovation Systems-NIS, Regional Innovation Systems-RIS, Sectoral Innovation Systems-SIS, and Complex Innovation Systems-CIS), it is noted that the concept of co-evolution of system actors has been given more attention in the recent years. However, co-evolution of more than one system (mainly sectors), remains a novel study area.

On the other hand, technology convergence literature remains a separate field than IS literature as well, which is reviewed to include scientific, market, and lately industry convergence studies in recent years. Technology management studies outline the importance of technology convergence from the firm perspective. In addition, methods to analyze technology convergence have been broadly discussed (Jeong et al., 2015). Given the role of technology convergence in leading and dominating next-generation technological innovation has been emphasized by a number of scholars (Athreye and Keeble, 2000; Morillo et al., 2003; Curran et al., 2010; Curran and Leker, 2011; Preschitschek et al., 2012; Karvonen and Kässi, 2013).

Despite the broad consensus on the considerable disruptive effect of technology convergence and the wide recognition of technology convergence by diverse economic actors, technology convergence has remained an abstract phenomenon. Few studies have empirically investigated how technology convergence has evolved at the macro level that encompasses the entire technological domains (Roco and Bainbridge, 2002; Curran and Leker, 2011; Jeong et al., 2015). In other words, few studies provide a comprehensive and evidential insight as to the landscape of technology convergence (Jeon et al., 2015).

Additionally, in accordance with the research questions, literature related to IS in the perspective of industry convergence is also reviewed, since the main research unit aimed in this thesis is sectors. It is found that a coherent framework and practical methods lack for understanding and dealing with technology convergence (and industry convergence), especially its disruptive effect over forming new sectors. Moreover, there is no single study covering the analysis of co-evolution of two dominant sectors regarding convergence from the IS literature perspective.

Since the main research unit is sectors, more attention is devoted to SIS literature. It is found that the work on SIS approach has concerned dynamics of one dominant sector (which are firms, other actors than firms, networks, demand, institutions, knowledge creation, the basic proposes of interaction, variety generation, selection, and co-evolution of these dynamics within the sector). Thus, it focuses on exchange and co-competition in a co-evolutionary perspective. While, SIS approach also pays attention to the links, complementarities, and interdependencies of related (supportive) sectors and sees them as crucial for forming sectoral boundaries, still the same approach includes gaps to explain the effect of technology and industry convergences over cross-sectoral dynamics.

Moreover, demand-side innovation policies literature is also reviewed. In compliance with the main research question, the relation between the technology-push and market-pull effects as in the push-pull dynamic between technology convergence towards market convergence and the formation of industry convergence is presented. The literature review of the thesis is presented as **“Chapter 2 - Theoretical Background”** and the main elements of CSIS approach are formulated. Concerning the main purpose of this thesis, all of these findings are used as inputs to develop the analysis method for CSIS approach (Step 3) and it is implemented for the case study (Step 4) which can be seen in Figure 1.1.

Step 2 is “Descriptive Study” and presented as **“Chapter 3 - Descriptive Study of Cross-Sectoral Dynamics”** with two sections. Descriptive study is undertaken as complementary to “Chapter 2 - Theoretical Background” for a better understanding of the sectors that are transforming due to the effect of convergence (especially technology convergence), that show cross-sectoral and co-evolutionary aspects. For this matter, the focus is put on “converging industries” and “industry convergence” terms. With the descriptive study, a wider observation could be made to fulfill the need to include the cases in the convergence literature to highlight the gaps regarding systemic approaches. Therefore, the findings of the descriptive study contributed to the formulation of the main concept of CSIS approach. Moreover, the results of this study are also used as inputs for the selection of the sectors for the case study. Accordingly, the first section is presented as **“Section 3.1 - Descriptive Research of Cross-Sectoral Dynamics”**. For this section, a bibliometric analysis is conducted based on scientific publication data on SCOPUS Database¹ between the years 2007-2017 that are retrieved with the keywords “converging industries” and “industry convergence”. Co-occurrence of terms and co-authorship analysis are made based on countries via VOSviewer². In addition, an extract of a review is done from the most related publications.

¹ In this thesis, SCOPUS Database is preferred for the analysis of scientific publication data, as it is reclaimed as the largest bibliographic database, while offering special tools for advanced research via keywords and visualization of search results which assisted in developing better search queries. SCOPUS Database also developed a standardization process for authors and affiliations using unique identifiers which is also beneficial for search results (Scientific Publications, 2020).

² VOSviewer is a tool used for visualizing bibliometric networks mostly based on citation, co-citation, bibliographic coupling, keyword co-occurrence, and co-authorship networks. Network visualization illuminates relationships and links between entities in clusters. Visualization approaches can be distance-based, graph-based (e.g. network visualization, density visualization), and timeline-based (e.g. overlay visualization). In this thesis, keyword co-occurrence is extensively used. The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract, or keyword list. Co-citation is the frequency of two documents that are cited together. Similarly, bibliographic coupling is two documents that reference a common third document in their bibliographies. The advantage of using bibliographic coupling can be eliminating delay of citations. However, it is used for measuring similarity between two documents and observing related research done in the past. On the other hand, co-ownership analysis is used for observing collaboration patterns based on documents that share authors. VOSviewer is also a useful tool for text-mining using integrated natural language processing algorithms (van Eck and Waltman, 2014). Examples of text mining and visualizations can be retrieved from <https://www.vosviewer.com/text-mining-and-visualization-using-vosviewer>.

The second section is presented as **“Section 3.2 Cross-Sectoral Matching Analysis of Sectoral Dynamics Separately”**. This section is done based on a previously held study for fifteen sectors separately and is added to the descriptive study to see converging sectors independent from the boundaries and externalities that cause convergence.

The sectors that are examined separately and in a cross-sectoral manner are; automotive, machinery manufacturing and ICTs, energy, food, water, health, aeronautics and space technologies, construction, chemistry, metal industry and minery, furniture, ceramics, textile, and transportation sector.

In accordance with the purpose of this thesis, a cross-sectoral matching analysis of the prioritized subjects of “R&D Based Solutions for Sectoral Problems Study” is applied, and results are used as an input to the analysis method implemented for the case study and for the selection of the sectors, which are undertaken as a case study (Step 4).

Step 3 is “Proposing an Analysis Method for Cross-Sectoral Innovation System (CSIS) Approach”. This step is presented as **“Chapter 4 - Analysis Method Proposal for Cross-Sectoral Dynamics”**. After the determination of the main elements of CSIS approach via previous steps, the analysis method for the CSIS approach is formulated, related dimensions and indicators are derived from current methods and in accordance with the research question. The derivation process of the analysis method for CSIS approach is applied in detail in two parts, as a formulation and method. In addition, the related links and similar structural components between each model that are used to derive the analysis method are presented.

Moreover, methods concerning the mapping of IS and measuring convergence are examined while forming the analysis method. It is observed that current methods remain at the developmental level in that they use experimental methods or limited data boundaries; thus, they only partially show the nature of convergence. As a result,

Chapter 4 presents the design of the analysis method that is composed of both qualitative and quantitative methods, as well as data and tools employed in the case study.

Step 4 is “Case Study: Convergence and Co-Evolution of Automotive and ICT Sectors Based On CSIS Analysis Method”. As one of the results of the Descriptive Study (Chapter 3), automotive and ICT sectors are selected to test the proposed analysis method as a case study. This step has two sub-steps as in quantitative and qualitative analyses; and it is presented as “Chapter 5 - Case Study: Cross-Sectoral Innovation System Analysis for Automotive and ICT Sectors”, in two sections; “Section 5.1 - Quantitative Analysis” and “Section 5.2 - Qualitative Analysis”.

It is determined that industry convergence is a result of effects on sectors composed of science (knowledge), technology, and market convergence types. Therefore, all convergence types are analyzed respectively, in a cross-sectoral context. Meaning, each sector is analyzed from the perspective of the other sector concerning cross-sectoral dynamics via the keyword matching method. Sub-technology areas (TAs) and keywords for both sectors are used which are determined via series of extraction studies. Moreover, for the best perspective, both quantitative (bibliometric and trend analyses) and qualitative (structured contribution form for expert opinions) analyses are formulated, conducted, and evaluated. Sub-steps are reflecting the sub-sections of the case study. All analysis sections are composed of “scope and method” sub-section primarily, and “analysis results and evaluation” as the following sub-section.

Step 4.1 is “Quantitative Analysis”. In relation to the research question of this thesis, co-evolution of more than one dominant sector based on convergence is examined and cross-sectoral aspects are analyzed. Both quantitative and qualitative methods are applied. This sub-step is presented as “**Section 5.1 - Quantitative Analysis**”. It is determined that industry convergence (cross-sectoral aspects) is a result of effects on sectors composed of science, technology, and market convergence types. Therefore,

all convergence types are respectively analyzed and presented in three consecutive sections using related matching analysis methods. All analyses are conducted by using global data, however for the reason that this thesis is undertaken in Turkey, a special part for Turkey data is also added for each analysis, if available, and presented in Appendix E.

For “**Section 5.1.1 - Quantitative Analysis for Science Convergence**”, a bibliometric matching analysis is conducted using scientific publications/citation data between the years 2007-2017 in selected sectors. A bibliometric co-word analysis is held based on keyword matching from sub-technology areas using data from SCOPUS Database. In addition, co-occurrence and total link strength mappings are made based on author keywords and citations, using VOSviewer.

For “**Section 5.1.2 - Quantitative Analysis for Technology Convergence**”, a bibliometric matching analysis is conducted using patent/patent citation data between the years 2007-2017 in selected sectors. A bibliometric co-word analysis is held based on keyword matching sub-technology areas using patent data from Derwent Database. In addition, co-occurrence and total link strength mappings are made based on patent keywords and backward citations, using VOSviewer.

For “**Section 5.1.3 - Quantitative Analysis for Market Convergence**”, mainly a global trend analysis is done in two steps using strategies of main actors in both automotive and ICT sectors as a source in cross-sectoral matching analysis. Primarily, to gather a general overview of global market trends from international organizations are presented as “**Section 5.1.3.3 - Cross-Sectoral Matching Analysis Based On Global Market Trends**”. Continuously, as a first step, trends based on world markets and/or countries, national strategies of determined countries are examined for both sectors and presented as “**5.1.3.4 - Cross-Sectoral Matching Analysis Based On Determined Countries**”. As a second step, trends based on cross-sectoral strategies of determined dominant private sector actors of both sectors are examined and

presented as **“5.1.3.5 - Cross-Sectoral Matching Analysis Based On Determined Companies”**. As a result, global trend analysis based on dominant countries for both sectors is mapped by main KETs derived from automotive and ICT cross-sectoral convergence and level of focus (calculated as a metric due to coverage by R&D strategy, dedicated law, support mechanism, national prioritized area, a national initiative, landmark project, technology roadmap, etc.). To have a weighted understanding, determined KETs from country-based trend analysis are correlated with the five most related sub-technology areas both from science and technology convergence analyses. The total count of both scientific publications and patents between the years 2007-2017 are calculated per sub-technology area, as well as per country. In addition, global trend analyses based on dominant countries and dominant private sector actors are mapped by prominent KETs from automotive and ICT cross-sectoral convergence, the direction of cross-sectoral convergence, and level of focus.

Step 4.2 is Qualitative Analysis. This sub-step is presented as **“Section 5.2 - Qualitative Analysis”**. In addition to the quantitative analysis methods that are explained above, to get the perspective of distinguished sectoral experts on cross-sectoral dynamics, an expert contribution form is structured and conducted via an online survey system, called Limesurvey. The expert contribution form is structured in three main parts, two of them being compulsory. For the first part, prioritization of sub-technology areas of automotive and ICT sectors is asked respectively, taking into consideration the cross-sectoral dynamics (prioritization technique with a score of 1-5 is applied). The second part is given as optional and target statements for the evaluation of cross-sectoral dynamics are collected (for the Delphi Technique). As the third and last part, co-evolutionary dimensions of the cross-sectoral interaction between automotive and ICT sectors considering the types of convergence are asked. Questions of if sectors are transforming one-sidedly, or what kind of convergence has the most impact, etc. are directed to experts (weighting technique with a score of 1-10 is applied per convergence type). For the Delphi Technique a keyword cloud of KETs by using

Semantria is prepared. On the other hand, Sankey diagrams by using Sankeymatic, are presented for further evaluation.

As the **Step 5**, the results of the quantitative and qualitative analyses, which are conducted as a case study, are presented as a separated section with the evaluation after the “scope and method” sub-section of every related analysis section, as aforementioned. Analysis results and evaluations from the case study are used for **Step 6** as input for the conceptualization study, which is presented as “**Chapter 6 - Conceptualization of Cross-Sectoral Innovation System (CSIS) Approach**” as a contribution to the IS literature and complementary of current IS approaches. Finally, **Step 7** is presented as “**Chapter 7 - Conclusions**” covering further research discussions and policy remarks.

1.5. Scope of the Dissertation

This thesis mainly aims to address the research question of whether there is a cross-sectoral co-evolution process based on convergence, particularly technology convergence, in the perspective of IS literature.

In this regard, the scope of the “sector” is taken as defined in SIS approach by Malerba (1999, 2002, 2004, 2009), and the terms “industry” and “sector” are used in the same scope.

That sections of an industry regarding a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products and that sectoral boundaries not being as given and static; that changes over time through co-evolutionary processes and regards knowledge as a key element.

Scoping “cross-sectoral” is also very determinative in this thesis. Because, in general, the term “cross-sectoral” is used for defining the collaboration of different actors of an R&D and innovation ecosystem, such as university-private sector collaborations

(SSIR, 2018). According to Bornkessel et al. (2016), the term “cross-industry” is also used for collaborations, while also covering industry convergence.

Since in this thesis focus put on the perspective of the SIS approach, consecutively, the scope of “cross-sectoral” is determined following SIS approach. In addition, the terminology of the European Science Foundation is considered. The term cross-sectoral is examined within *“the framework of multidisciplinary and cross-disciplinary research topics; and basicly defined as the convergence, fusion, and interactions of two or more different sectors.”*

Moreover, regarding the main research question of this thesis, the focus has to be more on the “convergence” term while defining “cross-sectoral”. Because, according to Curran (2013) and Sharp (2011), the term “convergence” is also defined in many ways depending on the subject. According to Sharp (2011), convergence is *“the merging of distinct technologies, processing disciplines, or devices into a unified whole that creates a host of new pathways and opportunities.”* Additionally, convergence is defined as *“advanced with the coming together of different fields of study through collaboration among researchers and the integration of approaches that were originally regarded as contradictory.”* Moreover, convergence is stated as a new paradigm *“that can yield critical advances in a broad array of sectors, from health care to energy, food, climate, and water.”*

As it can be seen, Sharp (2011) joining many others, defines convergence as a revolution, a paradigm shift, and not just within a discipline as in Thomas Kuhn’s terms. In other words, convergence is defined as a revolution that relies on a new integrated approach for achieving advances and not only on scientific breakthroughs.

In the convergence literature, one of the newly adopted terms is “industry convergence”. Which can also be used as “sectoral convergence”. However, the general term is accepted in this thesis, and no need for change is considered. According

to Hacklin (2008), industry convergence leads to the co-sharing of markets, value chains, and even technologies, related industries may face new consumer groups, new parts of industry value chains in other industries, as well as new functional values of existing products or technologies of other industries. In other words, industry convergence introduces *“complementary or substitutionary offerings across industries, which causes creative destruction in their corresponding markets and eventually leads to the emergence of an entirely new industry.”*

As can be seen, the definition of “industry convergence” is completely compatible with the research question and the scope of “cross-sectoral” aspects of this thesis, and is used as such. However, this definition does not entirely cover the co-evolution of cross-sectoral dynamics under the scope of this thesis, as well as the knowledge and technology-bases of the sectors, correspondingly. Therefore, for reflecting the scope of this thesis the term “cross-sectoral convergence” is also used. Nevermore, regarding this integration, the need for the investigation of the term “industry convergence” emerged, therefore it is separately examined under **“Chapter 2 - Theoretical Background”**.

In the convergence literature, it is discussed that in a given industry, convergence can be viewed from a different industry perspective, that is, between industries (between-industry convergence) and within an industry (within-industry convergence) or the scope of industry (Hacklin, 2008). All three perspectives are seen related to the scope of this thesis. For instance, in the case of between-industry convergence, two distinct industries overlap, as in the case of convergence between the manufacturing and the service industries, or the automotive and ICT sectors. In the case of within-industry convergence, convergence occurs among sectors within industries. Manufacturing of automobiles or electronics within the manufacturing sector can be given as examples. Therefore, in this case where there is a third distinct industry, covering sub-sectors of two other distinct industries.

Industry convergence can also be considered from the perspective of dynamics. In other words, trends and patterns of convergence can vary among industrial pairs, where the degree of industry convergence is the intensity of overlapping between industries. The degree of convergence can be high for some industrial pairs with large overlapping areas but can be low or even zero for other industries. This is still a process of convergence that might lead to the formation of a new industry, and the degree of convergence can be heterogeneous across different industry pairs.

Finally yet importantly, from the discussions of the convergence literature, it is stated necessary to examine the scope and dynamics of industry convergence, the understanding of the development processes of industry convergence at different stages of development, from the supply and demand sides. In this regard, dynamics of supply and demand sides are also investigated under **“Chapter 2 - Theoretical Background”** of this thesis.

1.6. Researcher’s Motivation and Significance of the Study

Recent developments show that technology convergence, and evidently industry convergence, represents the most fundamental growth opportunity for economies and businesses because sectoral boundaries are getting blurry and/or defined from scratch by shifting the focus from individual products to cross-sectoral value chains that depend on an ecosystemic perspective (Gartner, 2014). Disruptive and key enabling technologies (KETs) that are mutually created by the effect of the convergence, have the power to change the fundamentals of economies, businesses, and innovation systems. For instance, with the effect of technology convergence, the dominant economic sector is being created by one or more than one converging sector that, in turn, provides the infrastructure for wealth creation by all sectors. It should also be emphasized that this situation only shows an increasing trend. Moreover, an IBM study presents that two-thirds of global CMOs see convergence, especially industry convergence, as the biggest trend that it eclipses any of the other trends they anticipate

in the coming three to five years (such as cyber risks, alternative financing mechanisms, the sharing economy, and so on). In addition, 60% of CMOs expect more competition to come from companies outside of their sector (IBM, 2016). This is a challenge witnessed today, that big platform companies such as Google and Amazon, find it easier to work through the value chain horizontally and cross-sectorally. The boundaries between sectors are eroding, as companies in one sector apply their expertise to others – bringing the previously separate sector together and sometimes redefining the new sector that they are not currently classified. Factors caused by technology and market convergences are transforming the competitive landscape together.

These examples, as well as challenges, vary from traditional sectors to high-tech sectors; such as agriculture, finance, retail, healthcare, automotive, manufacture, media, medicine, etc. In the end, this increasing trend is related to the fast development of technology and digital transformation; however, technology can not be seen as the only dimension. Therefore, without studies focused on technology convergence and co-evolution of cross-sectoral dynamics, the transformation of new dominant sectors and innovation systems (dynamics of the innovation systems and sectors), as well as the impact of KETs, can not be understood. It is critical that policy makers understand which technologies will matter in the near future to develop proactive strategies accordingly (MGI, 2013).

There are separated convergence and innovation system works of literature. However, existing studies rely on the interaction and co-evolution of the sectors and actors of innovation systems. There are also studies regarding the effects of technology convergence over sectoral change and studies considering vertically related sectors (such as the aircraft industry), or co-evolution of upstream and downstream industries and network dynamics. Therefore, the current literature and methodological analyses are not from an integrated perspective of both convergence and innovation system

literature, they do not focus on co-evolution of two or more dominant sectors and transformation of new dominant sectors.

Finally yet importantly, innovation literature places a great deal of emphasis on an interdisciplinary (including multi- and cross-disciplinary) approach, which considers innovation as an interactive process among a wide variety of actors (Edquist, 1997). Relatedly, the importance of a cross-sectoral approach increases rapidly, considering contemporary aspects.

In the end, this thesis has two key contributions, one is methodological and the other is theoretical. This thesis aims to fill in the gaps for the aforementioned challenges by, first, proposing a method to measure how sectors change/transform, how new sectors form, how dynamics of innovation systems change in the presence of disruptive convergence effect, especially technology convergence. Secondly, by conceptualizing a Cross-Sectoral Innovation System approach in complementary of current IS approaches.

CHAPTER 2

THEORETICAL BACKGROUND

To seek guidance outside of science and technology is negligence, ignorance, and deviation from the right path. It is imperative to understand the evolution of science and technology in every minute of our lives and to follow the progress in time.

– Mustafa Kemal Atatürk

Technological change and the level of technological development are seen as the most important reasons for the economic growth of countries, and even radical changes in the society and economic structure. Economically disruptive technologies, such as today's semi-conductor microchips, sensors, internet of things, mobile technologies affect the way people live, work and emergence of new business models, and the change of the functioning of existing actors of the R&D and innovation ecosystem, like how steam power had an impact in the Industrial Revolution (MGI, 2013).

According to the Harvard Business Review (2012), one of the most important trends that affect the new economy is convergence. Regarding the convergence trend, it is stated that the dominant sector in the new economy is formed by the convergence of two or more sectors. The dominant sector provides the infrastructure of competition and economic contribution of all the sectors that constitute itself. As fast as technological development, convergence is becoming the basis for all sectors, while the dominant sector is also affecting all other sectors and fields such as education and scientific research to a great extent.

According to the same resource, other trends that affect the new economy are given as information, digitalization, visualization, molecularization, internetworking, disintermediation, innovation, personalization and presumption, immediacy, and globalization. It should be considered that these trends are triggering each other and the formation of disruptive technologies.

In line with these trends, economic, sectoral, and technological constructions are changing and new economic constructions, new sectors, and new technologies are forming. As a result, the proximity of the two structures and the cross-sectoral approaches are also increasing.

In recent years, there has been an increase in research of system approaches for studying innovation. The various system approaches, whether national, regional, or sectoral, have been widely used to map and explain interactions between actors of the innovation ecosystem, mainly firms and organizations that generate knowledge (Maskell et al. 1998).

However, recent developments show that (technology) convergence is a driver for new economy and innovation systems (OECD, 2015 and 2017a, respectively). Such that, the dominant economic sector is being created by more than one converging sector that, in turn, provides the infrastructure for wealth creation and innovation in all sectors. It is widely accepted that the developed world has changed from an industrial economy based on steel, automobiles, and roads to a new economy built on silicon, computers, and networks. There are new dynamics, new rules, and new drivers for economic development and the change is faster than ever. It is believed that competition between industries, innovation, and core technologies is happening through the knowledge exchange and studies among interested parties who have complementary technological competencies. Accordingly, a research based on knowledge-driven economies can be used effectively in analyzing factors of

comparative advantage and motives of convergence, technology convergence in particular, among industries (Kang and Oh, 2012).

Technologies that are economically destructive in nature (mainly key enabling technologies), such as ICTs (semiconductor chips, internet, mobile technologies), nanotechnology, and biotechnology are considered to have the potential to disrupt the status quo, thus alter the way people live and work, and rearrange the roles of actors in the current innovation systems. Therefore, policy makers must understand which technologies will matter in the near future to develop proactive policies accordingly (MGI, 2013).

However, there is little research that compares innovation system (IS) approaches by treating the recent convergence trend as the central theme. For instance, current IS literature focuses on technological change through a technological evolution analysis, a perspective that is linked to recent studies on economic growth and industry dynamics.

Moreover, up to now, the work on sectoral innovation systems (SIS) approach has concerned dynamics of one dominant sector (which are firms, other actors than firms, networks, demand, institutions, knowledge creation, the basic proposes of interaction, variety generation, selection and co-evolution of these dynamics within the sector). Thus, it pays a lot of attention to exchange and co-opetition from a co-evolutionary perspective. While, SIS approach also pays attention to the links, complementarities, and interdependencies of related/supportive, sees them crucial for forming sectoral boundaries, however, it remains inadequate to explain the impact of technological and industry convergence over cross-sectoral dynamics.

Thus, the major aim of this thesis is to integrate ongoing systems of innovation studies and to provide a better understanding of the cross-sectoral point of view regarding the technology convergence trend and to understand if there is a co-evolution between

sectors while developing a methodology to analyze and model cross-sectoral innovation system (CSIS) approach.

The research question of whether there is a cross-sectoral co-evolution process based on technology convergence is determined by focusing on the analysis of technology convergence, (cross-sectoral) co-evolution, and industry convergence from the perspective of IS literature. For this matter, the inadequacies in the current innovation system literature to determine the effects of technology convergence over co-evolution of more than one dominant sector are examined and the view of CSIS approach is determined.

In this chapter, literature related to IS in the perspective of technology convergence and co-evolution is reviewed in two parts. In compliance with the maturity level achieved in the notion of IS literature (National Innovation Systems-NIS, Regional Innovation Systems-RIS, Sectoral Innovation Systems-SIS, and Complex Innovation Systems-CIS), it is noted that the concept of co-evolution of system actors has been given more attention in the recent years. On the other hand, the co-evolution of more than one system -mainly sectors- remains a brand new area of research.

As the third part, literature related to IS in the perspective of industry convergence is also reviewed since the main research unit aimed in this thesis is sectors and there is a huge trend of converging industries.

Table 2.1 presents all of the findings and comparisons for IS literature and demonstrates the possible benefits of CSIS approach regarding the following nine criteria:

- (1) Definition/Main Unit of Analysis
- (2) Boundaries of the Sector/Relation Between Different Sectors
- (3) Focus on Technology Convergence

- (4) (Cross-Sectoral) Co-Evolution
- (5) Focus on Industry Convergence
- (6) The Emergence of New Sectors
- (7) Co-evolution of Internal and External Factors of Sectors
- (8) Focus on KETs
- (9) Interrelation Between IS Approaches

Finally, demand-side innovation policies literature is also reviewed. In compliance with the research question, the relation between the technology-push and market-pull effects as in the push-pull dynamic between technology convergence towards market convergence and the formation of industry convergence is presented.

The findings of the literature review suggest that in regard to technology convergence in IS literature mainly SIS approach comes forward. There are also adequate mentions in NIS approach, few mentions in RIS approach, and no mentions in CIS approach. However, since technology convergence is the main focus of this thesis, all IS approaches are examined in detail and presented as separate parts.

According to OECD (2015 and 2017a, respectively) convergence (mainly technology convergence) is a driver for the new economy and innovation systems. The literature focuses on technological change through a technological evolution analysis, a perspective that is linked to recent studies on economic growth and industry dynamics (Dosi and Nelson, 2010). Kang and Oh (2012) state that converging technologies are and will be knowledge-driven, multidisciplinary in the perspective of the NIS approach. Moreover, **converging technologies trigger the blurring of technological and sectoral boundaries**. It is discussed that technology convergence creates strategic impact and has a policy significance for NIS. On the other hand, coherent frameworks and practical methods for understanding and dealing with technology convergence lack (Roco, 2016). Moreover, **in convergence, there is a coordination challenge**. Coordination is necessary to create the infrastructure for knowledge creation. Such

infrastructures include physical instrumentation, tools, and coordination policies in research organizations and at a **national/regional level** (OECD, 2014a).

Most importantly, in the perspective of SIS (TIS) approach, technology convergence has been regarded as the **major source of innovations among industries and technologies**. From this point of view, Lee (2015) suggests that a systematic and broad understanding of technology convergence is crucial for continued innovation and economic growth. From SIS perspective, Malerba (1999) states that **links and complementarities** have to be taken into account for an understanding of the working and dynamics of sectoral systems. In the same study, multimedia is taken under focus. In multimedia, the convergence of **different types of demand and technologies has originated a new sector with continuously expanding boundaries and in which new entrants come in from each of the industries constituting the new multimedia sector, using new strategies more in tune with the new features of multimedia**. One of the weaknesses of the SIS approach is the changes in the knowledge-base, which change the types of relevant actors and the structure of networks in a sectoral system. Therefore, Malerba (2002a, 2002b) also emphasizes that the boundaries of sectoral systems are not static. In terms of “knowledge-base”, SIS approach assumes that often **more than one technology exists in a sector and usually there is a “technology-product matrix” in any sector. However, these technologies are interdependent and complementary** (Malerba, 2004). According to Malerba and Adams (2014), recent research in SIS requires expansion of the type of sectoral systems, catching up in different sectoral systems and simulation models. One of the most recent studies in regard to convergence of ICTs, it is mentioned that static and rigid perspectives need to be replaced by frameworks and models that allow observing the change of the dynamics (Malerba and Adams, 2014).

The co-evolution aspect in IS literature takes a greater focus. However, when it comes to “cross-sectoral co-evolution” there is almost no reference in the whole IS literature. Few references are stated in SIS and NIS approaches respectively, nevertheless, there

are no references in RIS and CIS approaches. Except that it is observed that regional firm populations and private-sector innovation co-evolve with related public research activities in the respective region (Blakenberg and Buenstorf, 2016). Thus, in this chapter, only NIS and SIS approaches are given in detail. From NIS perspective, it is accepted that sectors co-evolve with their institutional environment (Nelson, 1994) and that it is impossible to find a single successful sector without strong and challenging supportive and related sectors (Porter, 1990). Concerning SIS (TIS) approach, heterogeneity within sectors is considered as a key element, also where **links and complementarities are defined between the dominant sector and a related sector** (Malerba, 1999). Boundaries of the sectoral system change because of the dynamic links and complementarities (Malerba, 2002a). Complementarities also include interdependencies among vertically or horizontally related sectors, the convergence of previously separated final products, or the emergence of demand from the existing one. Therefore, SIS perspective suggests that interdependencies and complementarities define the real boundaries of a sectoral system. Moreover, technology convergence denotes **the emergence of co-evolutionary spillover between previously unassociated and distinct knowledge-bases, giving the rise to the erosion of established boundaries that isolate sector-specific knowledge** (Hacklin, 2008).

Lastly, looking at industry convergence in IS literature, a few references are given in SIS and NIS approaches respectively; nevertheless, there are no references to industry convergence in RIS and CIS approaches. Kim et al. (2015) state that there is blurring of industrial boundaries and new dynamics across different industries that triggers co-evolution within industry convergence. In the perspective of NIS, Zang (2014) states that cross-sectoral convergence can lead to changes in the nature of technological innovation, product development, value-creating or value-adding processes, and consumer behavior. Thus, such convergence requires changes in the existing institutional structure or the creation of new ones to accommodate the different needs of different industries. Moreover, SIS (TIS) approach suggests that industries have always been distinguished by their distinct products, actors, knowledge, technologies,

and demand structures (Bröring et al., 2006). It is accepted that new knowledge may also originate in other industries, that are not part of the current SIS, and which can constitute external sources (Malerba, 2002a; Gerum et al., 2004).

The recent study that Geum (2016) conducted employing practical data on 100 successful Korean cases of industrial convergence to analyze how industrial convergence takes place shows that the **notion of “industry” is changing and innovation no longer occurs within one dominant industry**. Moreover, there is another study examining industry convergence as a fundamental concept in the mobile communications sector to understand the industrial dynamics and business strategies and the transformation of its system of innovation (Gerum et al., 2004). However, it does not show industry convergence of more than one dominant sector.

Evidently, the aforementioned summary of the literature review brings out the notion and/or necessity of a Cross-Sectoral Innovation System (CSIS) approach that constitutes of a systemic perspective of more than one dominant sector. The following sections are presenting the details of technology convergence, cross-sectoral co-evolution, and industry convergence in the IS literature (NIS, RIS, SIS, and CIS approaches), respectively.

2.1. Technology Convergence

In the convergence literature, the first use of the term “convergence” is attributed to Rosenberg (1976), who defined the changes in the machine tool industry in the second half of the 19th century by using the expression “technology convergence,” to contrast with “sequences of parallel and unrelated activities”. According to Curran and Leker (2011), Rosenberg employs the term to describe processes used by unrelated industry sectors and different stages of tool production. Today technology convergence is a well-known trend and it is accepted as the creation of new technology and product in the innovation process. Especially due to the fast development of ICTs and digital

transformation today, many examples of technology convergence can be given. One of the good examples is bio-informatics converging from biotechnology and ICTs. This new area of genetic information technology was created by applying capabilities of storing and analyzing from information technology to biology, and there is strong competition among advanced countries to acquire a competitive advantage in this field (Kang and Oh, 2012). Accordingly, Furukawa et al. (2015, p. 280) emphasize that emerging technologies (or KETs) are shaped by science-based innovation, which shows high potential for creating new sectors or transform existing sectors.

On the other hand, Dosi and Nelson (2010) and Lee et al. (2015, p. 318) state that the evolutionary economics literature covers technological change with various technological evolution analysis studies linked to economic growth and industry dynamics. Moreover, Lee et al. (2015, p. 318) emphasize that technology convergence triggers different technologies to create a new domain and evolve themselves, resulting in promising scientific and technological areas and key enabling technologies that can be observed. In particular, Allarakhia and Walsh (2012) state that according to the Neo-Schumpeterian approach; convergence across various fields creates new opportunities that can offer a new competitive edge to companies and nations.

Regarding their study on science parks, Kang and Oh (2012, pp.16-17) state that knowledge exchange and complementary technological competencies of related actors play a crucial role in the competition between industries, innovation, and core technologies. Convergence is interlinking a broad range of knowledge-bases. Therefore, technological innovation through technology convergence happens via collaboration among lateral industries and very different industries that do not share any knowledge-bases as well.

Curran and Leker (2011, p.257) categorize convergence as;

- (1) Science convergence that merges different scientific disciplines or areas,

- (2) Technology convergence that combines technologies of different application areas, and,
- (3) Industry convergence that unites sets of companies with different technology-bases, application areas, and target groups in various markets.

According to Hacklin et al. (2009, pp.725-728) and Kim et al. (2015), convergence occurs in four stages:

- (1) Science (scientific or knowledge) convergence,
- (2) Technology (technological) convergence,
- (3) Market (applicational) convergence,
- (4) Industry (industrial) convergence.

Figure 2.1 shows the convergence terminology and process used by Kim et al. (2015). The same convergence terminology is used in this thesis. On the other hand, as Kim et al. (2015) state, in the literature, there are arguments about the process of convergence types. For instance, Hacklin et al. (2009) argue that the convergence process is sequential and that technology convergence leads to market and then to industry convergence. However, Curran and Leker (2011) suggest that scientific and technology convergences can lead to both market and industry convergences. Curran et al. (2010) also state that in the advent of each stage of convergence, the prior stages of convergence work as triggers of the convergence. Moreover, OECD (2014a)³ suggests that “*convergence occurs where scientific disciplines or KETs combine with other disciplines or KETs, and promise new or added value beyond synergies*” and makes a similar categorization as Curran and Leker (2011). As Bores et al. (2003)

³ According to OECD (2014a) convergence is categorized as;

- (1) Convergence at the level of scientific research: where previously separate disciplines of science and technology become interlinked in the co-production of a new field of scientific research,
- (2) Convergence at the level of manufacturing and product development; and,
- (3) Convergence in the embedding of technologies into socio-technical systems such as healthcare, logistics and food security.

suggest, convergence is affecting sectors that are concentrated with the delivery of data and content, as well as those that concern with their displaying, therefore convergence affects market dynamics because it implies the merging of different markets.

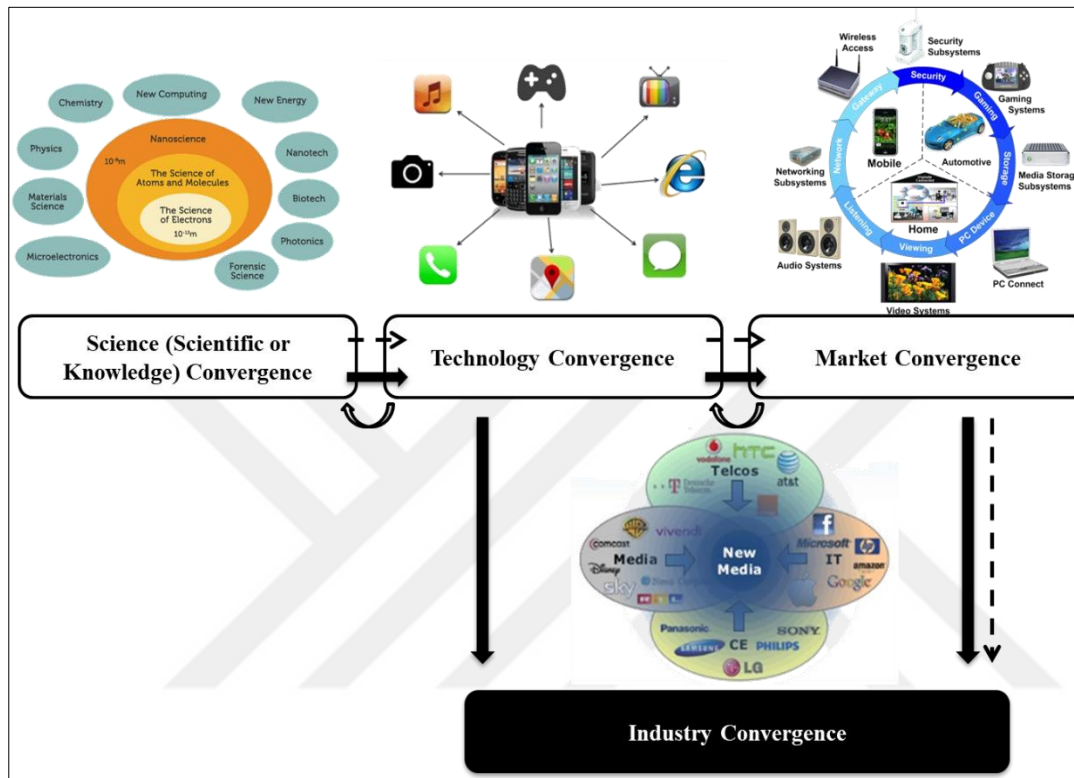


Figure 2.1. The Terminology of Convergence (Kim et al., 2015, p.1737, Edited)

In every convergence type, there should be an interactive process rather than a linear or sequential one. From this observation, semi-circle arrows are added between market, technology, and science convergences in Figure 2.1. Furthermore, among these, Hacklin et al. (2009), and Jeong and Lee (2015) recognize industry convergence, the point at which market convergence transitions into shifts in sectoral boundaries, as a major driving force of economic development through the impetus of technology convergence. Thus, industry convergence in IS approach is examined separately as the third part of the theoretical background (Chapter 2, Section 2.3).

From now on, the examination of technology convergence in IS literature regarding NIS, RIS, SIS, and CIS approaches is given in detail separately in the following sections.

2.1.1. Technology Convergence in NIS Approach

There are a few mentions of convergence, particularly technology convergence, in National Innovation System (NIS) approach. However, there is no adequate examination.

According to Athreye and Keeble (2000), converging technologies are expected to lead and dominate next-generation technological innovations, as crossing disciplinary boundaries by convergence make it possible for researchers to develop intellectual breakthroughs. Morillo et al. (2003) and Jeong and Lee (2015) state that this aspect of convergence can contribute to the increase in innovation capabilities of research and development (R&D) entities, thus it is crucial on the development of innovation systems. Relatedly, Kang and Oh (2012) took a macro-systemic approach emphasizing that traditional technology is material-oriented and unitary-disciplinary under the auspices of NIS.

Fukurawa et al. (2015, p.280), also state that emerging technology is diverse from the incremental improvement of an established technology. An emerging technology (which is also defined as key enabling technology) is regularly based on technology convergence. Moreover, an emerging technology often causes technological discontinuity and has disruptive effects on existing sectors, markets, and firms. Therefore, Fukurawa et al. (2015, p.280) emphasize that strategic R&D investment in emerging technologies helps to boost sectoral competitiveness, attracting significant attention from policy makers and administrators at the national level.

OECD (2014a) also refers to the impact of the emerging technologies based on convergence and states that adoption of convergence, emerging, and converging technologies requires a strategic policy, due to the complexity and uncertainty aspects, potential dual-uses, and the multiplicity of the challenges of different dynamics that converging technologies pose. Therefore, IS approaches at all levels are crucial.

2.1.2. Technology Convergence in RIS Approach

There are even little mentions of technology convergence in Regional Innovation System (RIS) approach. Kang and Oh (2012, p.17) who studied technology convergence and science parks, state that from the perspective of RIS, recent technologies are all information, interdisciplinary, and/or multidisciplinary oriented, therefore a micro systematic approach is needed. Current technologies are conducted in an interdisciplinary and/or multidisciplinary way, which mostly results in technology convergence and new converging technologies. Research on converging technologies is conducted in a situation of the destruction of technological and sectoral boundaries. Regarding Kang and Oh's observations, technology convergence is mainly knowledge-based, interdisciplinary, and/or multidisciplinary, and gets beyond the RIS with globalization.

2.1.3. Technology Convergence in SIS Approach

As aforementioned, emerging technologies are considered to have the potential to create new sectors and/or transform existing sectors (Fukurawa et al., 2015). Therefore, there are many mentions about how several sectors are affected by this trend. However, there is inadequate examination in the Sectoral Innovation System (SIS) approach, as its perspective does not involve studying more than one (dominant) sector. SIS approach focuses only on one dominant sector and takes other sectors as related/supporting sectors. In this manner, the transformation of the sectors nor the

changes in the dynamics of the sectoral innovation system due to trends like technology convergence are not analyzed directly under SIS approach.

In the literature, it is stated that technology convergence has been regarded as the major source of innovations among sectors and technologies (Gambardella and Torrisir, 1998; Curran and Leker, 2011; Karvonen and Kässi, 2013). Gambardella and Torrisir (1998) also reference Rosenberg (1976), who gives examples of technology convergence from the electronics industry, emphasizing the process by which different sectors come to share similar technological bases. On the other hand, in their analysis of the largest thirty-two American and European firms in the electronics industry by comparing their patents in computers, telecommunications equipment, electronic components, other electronics and non-electronic technologies, Gambardella and Torrisir (1998) argue that despite the effect of technology convergence firms could stay technologically diversified. However, recent studies show otherwise. For instance, Karvonen and Kässi (2013) state that technology convergence facilitates knowledge exchange among sectors and technologies, and generates new combinations of technologies, which lead to innovation. Technology convergence and technological innovation have been observed as the base of many sectors, such as telecommunications (Bigliardi et al., 2012, p.35; Grove and Baumann, 2008). According to a study by Lee et al. (2015), based on IPC co-occurrence from an IPC sub-class level (IPC 4-digit) perspective, 63% of the entire triadic patents underwent technology convergence. Therefore, understanding these patterns and applying them to reality, is important. In this regard, a systematic and broad understanding of technology convergence is considered inevitable in pursuing continued innovation and economic growth.

Moreover, Kang and Oh (2012) state that technological innovation through technology convergence is not only happening via collaboration among similar sectors but also via collaboration among lateral sectors. Similarly, Kang and Oh (2012) give an example from the geospatial sector that there was a time when remote sensing,

computer aided design (CAD), geographic information systems (GIS), global positioning system (GPS), and navigation technologies were different vertical markets served by different technology providers. However, recently these various geo-enabled technologies are converged and their respective markets became more horizontal. Therefore, there rises a challenge for the new sectoral dynamics, and innovation systems. For instance, Bezzina and Sanchez (2005) emphasize the challenge for regulators from the perspective of IS approach who have to respond to technological innovations and deal with changes in their frameworks and legislation. One of the challenges is that technology convergence requires a transition to a cross-product, cross-platform and cross-sectional licensing. More precisely these type of challenges in the dynamics of the sector requires better examination of the new SIS dynamics in the cross-sectoral perspective.

On the other hand, it is important to consider not only the dynamic interaction among the technological, political, and market areas but also the speed differences of changes each of them has. Technological innovation is more dynamic than the competition dimension of the market and it is more dynamic than the adequacy and stability of public policy and the legal framework.

However, technology convergence may not only make particular sectors technologically related in processes but can also give rise to the dominance of certain emerging technologies. Which can also be stated as key enabling technologies (KETs). Athreye and Keeble (2000) emphasize that technology convergence is linking sectors that may seem unrelated in the market, but common in their technological (hence knowledge) bases. In this matter, according to the patent analysis made by Kim and Kim (2012), emerging sectors are characterized by the rapid development of technologies based on a gradually broadening range of scientific and technological areas which increases the necessity of cross-, multi-, and interdisciplinary research. At the same time, to meet the more complicated customer demands, the merging of different technologies has become indispensable. The convergence of technologies

and underlying knowledge-bases has accordingly induced a variety of sectoral points of inflection. Various sectors have started to provide products and services with similar functions, which result in blurring of market boundaries (Kim and Kim, 2012).

From the given example above, the semiconductor sector is another example of sectoral transformation. Lee and von Tunzelmann (2005) state that for the semiconductor sector the complexity of the production process caused a high cost of production and originally organizationally disintegrated processes saw a shift of combining the main engineering and manufacturing tasks (for example, design houses, mask houses, wafer companies, foundries, back-end processing, and electronic packaging). As OECD (2014a) stresses cost and power consumption are key drivers in the digital market. Therefore, this type of process of technology convergence that is observed in the semiconductor sector is also leading to organizational convergence in the manufacturing process and product supply chain that requires an increasing amount of different collaboration skills, co-design, and co-creation between actors. This not only means a new sectoral approach but also different dynamics for the sectoral ecosystems.

Hacklin (2008) identifies convergence as the process along an evolutionary trajectory, representing a foundation for determining the dynamics of innovation. Aminuallah et al. (2015) agree with this definition; also refer to the observation between technology convergence and open innovation in their research regarding technology convergence and SIS perspective for biobased chemical firms in Indonesia. They define the emergence of biobased chemical products as the convergence of green chemistry with industrial biotechnology. While they are focusing on technology convergence, they also cover cross-sectoral dynamics and the emergence of new sectors. For that matter, they specifically emphasize that SIS policies should be addressed to enable bio-based chemical firms to realize the opportunities via technology convergence. While the rapid change in the innovation environment is accelerating, particularly in digital convergence, standards and networks, it leads to the widespread trend of companies

engaging in different capabilities and external knowledge sources as a way to extend their sectoral boundaries. This process extends and transforms the dynamics of the sectors (hence SIS) in an evolutionary trajectory. Furthermore, Jang (2009) observed that entrepreneurship based on technology convergence is formed through cross-sectoral research collaborations. Thus, diverse cross-sectoral research collaborations generally result in more strategic and entrepreneurial technology convergences and the formation of new sectoral dynamics, evidently industry convergence as well.

In recent years, the convergence of biotechnology, nanotechnology, and ICTs, enabling technologies or general purpose technologies, has raised expectations of rapid future technological change in the coming decades. For example, the expectations that new materials combined with lower energy inputs and the IoTs are expected to allow new forms of production that remove the need for scale economies and enhance efficiency as well as consumer utility and public service delivery. Therefore, technology in isolation is rarely the driver of system-wide change. OECD (2015) states that system innovation poses a challenge for policy makers as changes formed by technology and innovation are generally endogenous processes where the main drivers are entrepreneurial and market forces. System-wide change requires innovation not just in technology but also in social systems and the relationship between the social and technical systems.

Now, looking a little bit more closely from the perspective of SIS approach, Malerba (1999) states that sectors differ along several dimensions related to technology, production, innovation, and demand. Furthermore, that they differ in the type and degree of change. Studies in evolutionary economics have focused on differences in knowledge, learning, and innovation among sectors and have related sectoral differences to the technological and knowledge environment and the accumulation of competencies by firms. Similarly, the innovation and technological system literature has stressed that in the innovative process the interaction among actors, and the role of non-firm organizations and institutions differ across sectors and technologies.

According to SIS approach;

A sectoral system of innovation and production is composed by the set of heterogeneous agents carrying out market and non-market interactions for the generation, adoption and use of (new and established) technologies and for the creation, production and use of (new and established) products that pertain to a sector ("sectoral products").

A sectoral system consists of a knowledge base that interlinks technological aspects, and also key links and complementarities among products, knowledge, and technologies, which affect the creation, production, and use of the products (Malerba, 1999). SIS approach also gives importance to links and complementarities at the input and demand levels. These complementarities are observed as both static and dynamic while covering the interdependencies across vertically and/or horizontally related sectors, and the convergence of previously separated end-products, or the emergence of demand from the existing one. Thus, interdependencies and complementarities are stated to define the real boundaries of a sectoral system. They may be at the input or the demand level and may concern innovation, production and distribution (Malerba, 1999).

Two examples may show that links and complementarities have to be taken into account for an understanding of the working of an SIS. For instance, in new multimedia sector, the convergence of different types of demand and technologies has originated a new sector with continuously expanding boundaries and in which new entrants come in from each of the sectors, using new strategies more in tune with the new features of the multimedia sector. Hence, the dynamics of SIS continuously change.

Another example is given from the computers sector. Until the 1980s, dynamic complementarities and linkages have kept hardware and software interdependent and have consequently affected the vertical organization and strategies of computer firms. Later on, some of the complementarities have become less strong and standard

interfaces have emerged, thus leading to the creation of strategies of specialization in computer hardware or software (Malerba, 1999). Today, all of the sub-technology areas of ICTs, while they are also converging technologies, can still be considered as separated sectors and SIS approach can be adapted respectively. However, SIS approach comes with challenges when the sector in focus consists of more than one dominant sector that is distinct through their sectoral dynamics and co-evolutionary processes.

Nonetheless, weaknesses faced by SIS approach as stated by Malerba after investigating European SISs (2002b) are given below:

- (1) Knowledge at the base of innovative activities is changing continuously; this change is affecting the boundaries of sectoral systems.
- (2) Changes in the knowledge-base change the types of relevant actors and the structure of networks in a sectoral system.
- (3) The role of national as well as sector-specific institutions that are relevant for innovation differs among sectors (sectors require differing balances in the interplay between national and sectoral institutions supporting innovative activities).
- (4) The co-existence of global, national, and local boundaries is present in most sectoral systems.
- (5) Co-evolutionary processes are taking place in all sectoral systems. More precisely changes in the knowledge-base or in demand affect the characteristics of the actors, the organization of R&D and the innovative process, the type of networks, the structure of the market, and the relevant institutions.

Malerba (2002b) also states that all these variables, in turn, lead to further modifications in the technology and again in the knowledge-base and demand, and so on. Since they are affected by the knowledge-base and technologies as well as by the

type of demand, links and complementarities among artefacts and activities, the boundaries of sectoral systems are not static.

For surely, SIS approach helps policy makers to have a better understanding of structure and boundaries of sectors, actors and their interactions, learning, and innovation processes specific to a sector, types of sectoral transformation, and factors at the base of the differential performance of firm and countries in a sector (Malerba, 2004, p.11). In the last decade, research in sectoral systems has progressed along three broad lines of inquiry (Malerba and Adams, 2014):

- (1) Expansion of the types of sectoral systems examined (the variety of sectors using a sectoral system framework has expanded significantly).
 - SIS framework can be used for examining broadly defined sectoral systems such as the ICT sector, where the goal is to understand broader processes of integration between different technologies, the convergence of previously separated industries, and the redefinition of sectoral boundaries.
 - Also a more narrowly defined system within ICTs (such as software) where the goal is to conduct a detailed analysis of the actors, knowledge-bases, and networks involved in specific innovative activities and to identify distinctive co-evolutionary processes (Steinmuller, 2004).
- (2) Catching up in different sectoral systems (different countries and national innovation systems) (Malerba and Adams, 2014).
- (3) Simulation models (better understanding of causal mechanisms that affect innovation and the dynamics of sectoral systems (Malerba and Adams, 2014).

Furthermore, Malerba and Adams (2014) put emphasis on the convergence of ICTs in their recent analysis from the perspective of SIS approach. They bring focus on the recent use and integration of new technologies in traditional sectors, or the presence of bio- and nanotechnology in so many sectors. They also emphasize that static and rigid perspectives need to be replaced by frameworks and models that allow observing

the change of dynamics. However, they do not define a new approach regarding the sectors mainly formed and changed by the effect of technology convergence. Hence, they accept the current approach.

Technology convergence leads to the disruptive progress that changes sectors and dynamics of respective innovation systems entirely. The aforementioned studies do not respond to the necessity of observing the transformation of sectoral boundaries and dynamics of the innovation systems while including more than one sector. This point of view brings the necessity of a **Cross-Sectoral Innovation System (CSIS)** approach and methodology. Figure 2.2 shows how the current SIS approach regards sectors that consist of more than one dominant sector based on convergence (mainly technology convergence), and how they should be regarded from the cross-sectoral and co-evolutionary perspective.

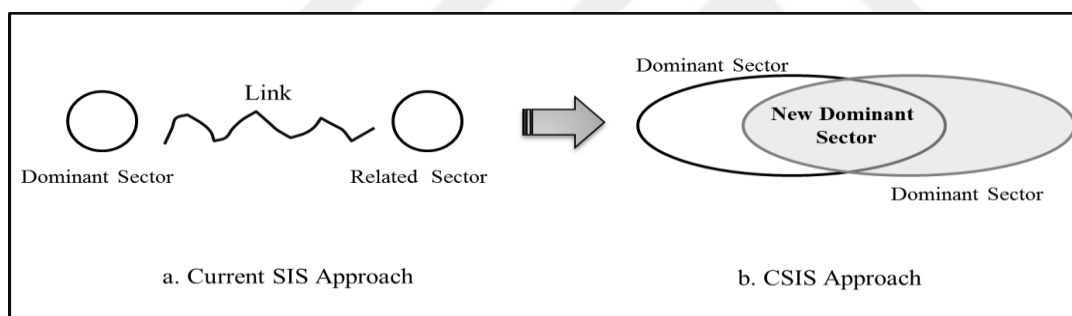


Figure 2.2. Current SIS approach versus CSIS Approach

2.1.4. Technology Convergence in CIS Approach

While it is difficult to accurately define a Complex Innovation System (CIS), it also has identifiable characteristics (Baranger, 2001; Amaral and Ottino, 2004). A CIS is defined as having a dynamic structure with interdependent constituents that interact in complex and non-linear ways. It is open in the sense that information flows across its boundaries, which in turn are difficult to identify. It has structures with different scales.

It shows emergent behaviors and patterns that are not caused by a single entity in the system. For instance, the stock market is a CIS that has emergent properties determined by the collective actions of investors (Blok, 2000). On the other hand, a CIS is self-organizing. For example, its emergent properties may change its structure or create new structures. Finally yet importantly, CIS is stated to have complex sub-systems. Looking at the aforementioned characteristics of CIS, defining formation of new sectors based on technology convergence seems possible. However, literature does not define CIS as composed of dominant complex systems and does not refer to the co-evolutionary perspective of system actors. Hence, CIS approach covers neither cross-sectoral nor co-evolutionary perspectives.

2.2. Cross-Sectoral Co-Evolution

In IS literature when it comes to “cross-sectoral co-evolution” there is almost no reference. Few references are stated in NIS and SIS approaches respectively, nevertheless, there are no references in RIS approach and CIS approach. Thus, only NIS and SIS approaches are given in detail and RIS approach is covered with featured points.

In the IS literature, co-evolution is proposed to be a theoretical framework to define interdependent dynamics of ecosystem actors, sectors, technological change, and the institutional environment. A co-evolutionary system means to have features that changes in each part of the system have causal effects on the subsequent evolution of the other parts. Because of the interactive and linked nature of innovation processes, the co-evolution concept resonates with the IS approach and highly accepted (Lundvall, 1992; Nelson, 1993, 1994; Malerba, 2002a; Murmann, 2003, 2013a, 2013b; Cooke et al., 2004; Soete et al., 2010, Blakenberg and Buenstorf, 2016, p.858). Murmann (2003, p.21) also emphasizes that a co-evolutionary system defines a broader sense that multiple entities are jointly and mutually evolving, rather than evolving together in the restricted sense. In that manner, in a co-evolutionary system,

interactions between actors (firms, customers, suppliers, universities, and public research organizations) are key to innovation. Institutional context, including the regulatory framework as well as cultural, scientific, and technological traditions play a key role as well.

From the sectoral perspective, Nelson (1994) suggests that public research is a key element of the institutional context that a sector co-evolves within. Particularly in the case of the formation of new sectors, this may include the argument that entirely new dynamics and new organizations (such as universities or government laboratories; or governance mechanisms) are required to form the knowledge-base and the competitiveness of the respective dominion. In this matter, Murmann (2003, 2013a, 2013b) presents a study of industry-science co-evolution in the 19th century synthetic dye industry resulting in the importance and relevance of these interactions between firms and public research and shows co-evolutionary perspective in the creation of a new sector. On the other hand, Blakenberg and Buenstorf (2016) observe the same output in their more recent study of co-evolution of regional firm population sizes, private-sector patenting, and public research in German laser research and manufacturing for over 40 years from the emergence of the industry to the mid-2000s. Therefore, the sense of co-evolution in the aforementioned studies is given from the perspective of technology and industry convergences, but between different actors of the sectoral systems. In that point of view, the cross-sectoral aspect of the co-evolutionary process comes forward as cross-sectoral between university-industry and such dynamics which are not in the scope of this thesis.

From the perspective of market convergence, Borés et al. (2003) state that the convergence affects those industries that are concerned with the delivery of data and content, as well as those that take care of their display, and will affect their market power because it covers the merging of different markets in the co-evolutionary perspective. On the other hand, Dawid and Wersching (2006) state that attainment of competitive advantage in newly converging industries is achieved through the

collaboration and networking among sectors that hold various technologies. Exchange and development of knowledge in this process are conceived as a collective asset not a by-product of technological innovation; rather accelerate new technology convergence and new products. In other words, Dawid and Wersching (2006) emphasize that a paradigm shift based on technology convergence does not only result in a disruptive impact in technologies or sectors but also has a self-organizing feature because it happens through the continuous and accumulated co-evolution of existing paradigms. Moreover, Kang and Oh (2012) state that technological innovation through technology convergence while happening via collaboration among unrelated or similar sectors, also happens via collaboration among lateral sectors. Therefore, technology convergence and the transition process should be observed closely. In addition, to adapt it is important to search for new technological innovation through networking between lateral sectors and the same kind/lateral inter-linking. This point of view brings on the matter of cross-sectoral co-evolutionary perspective based on technology convergence. From this perspective, Pagani (2003) describes digital convergence in particular as a co-evolutionary process where *“different sectors and technologies combine whereas they were initially less independent.”*

Furthermore, OECD (2014a) emphasizes that the process of technology convergence is also leading to organizational convergence, which also brings co-evolutionary aspects into the equation. For example, in the manufacturing process, an increasing amount of collaboration between actors in the co-evolutionary perspective is required; joint research and development are necessary, as well as shared between organizations and personnel that were previously segregated. Convergence in manufacturing, where the design and development of devices bring together organizationally separated actors with their specific skills and knowledge-bases into co-design, happens in a co-evolutionary perspective (OECD, 2014a, p.17). Li et al. (2013), suggest that current convergence literature offers a logical explanation of sectoral evolution. They also overview the mechanism inside the sectoral evolution to see that is not only derived

by technology progress within one sole sector, and on the contrary, it evolves cross- as covered in this thesis.

Moreover, Burrus (2013) regards a similar point of view saying that sectors all existed independent of each other and they had their associations, and they did not work with other sectors that were not related. Circumstances of today show that, sectors are converging and the possibilities are endless. Therefore, sectors are not isolated; on the contrary, there are exchanges of dynamics between the sectors. This point of view is especially emphasized due to the emerging concept of “Industry 4.0” (Figure 2.3). Industry 4.0 as a concept does not only cover the digital transformation of the sector and manufacturing processes, but also cross-sectoral co-evolution of dominant sectors in the context of convergence.

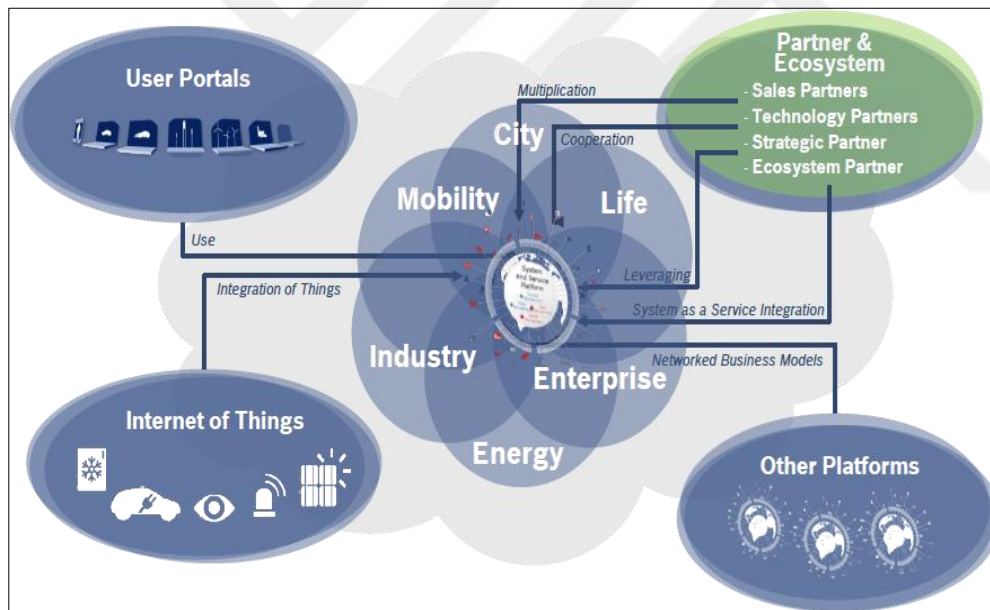


Figure 2.3. The Concept of Industry 4.0 (Burrus, 2013)

From now on, the examination of “cross-sectoral co-evolution” in IS literature concerning NIS and SIS approaches are given in detail.

2.2.1. Cross-Sectoral Co-Evolution in NIS Approach

The IS literature places a great deal of emphasis on an interdisciplinary and cross-disciplinary approach which considers innovation as an interactive process among a wide variety of actors (Edquist, 1997). However, there are a few references of “cross-sectoral co-evolution” in the IS literature. Frequently, the co-evolutionary perspective of sectors is examined within the concept of an institutional environment. For instance, Nelson (1994) states that sectors co-evolve within their institutional environment, that networks, organizations co-evolve over time and may change the pattern of linkages accordingly. It is also a common statement that knowledge, is not a factor that can be restricted within borders any firm, making competitiveness strongly depend on the relationships with external actors. Therefore, the process of interaction allows knowledge flows and learning processes that are essential for innovation. Knowledge flows and learning processes make actors of the innovation ecosystem co-evolve (Lundvall, 1992; Nelson, 1993; Edquist, 1997; Pietrobelli and Gorgoni, 2010).

From the perspective of understanding the transformation of NIS, Lundvall (2005) states that a focus on co-evolution of production structure, technology, and institutions are useful. In that regard, he argues that the most important reason for seeing NIS as a co-evolutionary concept is the focus on knowledge and learning. The analysis of IS may be seen as an analysis of how knowledge-base evolves through processes of learning and innovation.

Accordingly, learning and innovation are stated as strongly interconnected processes. Especially interactive learning is accepted as a socially embedded process. Lundvall (2005) also states that NIS differs in terms of knowledge-base regarding specialization in production. That, NIS is systemic in the sense that the different elements are interdependent in a co-evolutionary perspective; and that interrelationships matter for innovation.

2.2.2. Cross-Sectoral Co-Evolution in SIS Approach

There are rather more references in Sectoral Innovation System (SIS) approach for co-evolutionary perspective, naturally for cross-sectoral as well. SIS approach gives importance to links and complementarities at the input and demand levels. These complementarities are both static and dynamic. They include interdependencies among vertically or horizontally related sectors, the convergence of previously separated final products or demand from the existing ones. Thus, interdependencies and complementarities are stated as the key elements for the definition of the real boundaries of a sectoral system. They may be at the input or the demand level and may concern innovation, production, and distribution. Malerba (1999) emphasizes co-evolutionary processes that change sectoral systems. Malerba (1999) also states that SIS approach focuses on the dynamics and transformation of sectoral systems. Particularly, emphasis is put on co-evolutionary processes involving firms and other organizations, knowledge, technology, and demand. However, as aforementioned, the evolutionary literature proposes that sectors and technologies differ greatly in terms of the knowledge-base and learning processes. Nelson (1994) and Metcalfe (1998) discuss co-evolutionary processes from the perspective of interactions between technology, industrial structure, institutions, and demand. From the perspective of SIS approach, these processes are covered sector-specific.

Mowery and Nelson (1999) state that the transformation of sectors such as semiconductors, computers, software, pharmaceuticals, biotechnology, chemicals, medical devices, and machine tools shed new light on co-evolutionary processes over time and across countries. For example, Bresnahan and Malerba (1999) discuss that in the computer industry a co-evolutionary process involving technology, demand, firm structures, and institutions have characterized the industry and caused the transformation. Nevertheless, none of these discussions involves cross-sectoral co-evolution aspects.

Co-evolutionary processes are taking place in all sectoral systems. These processes are coming front as one of the many weaknesses of SISs as stated by Malerba for European SISs (2002b). Most importantly, as Malerba (1999, 2002a) states, the boundaries of sectoral systems and characteristics of actors are affected by the knowledge-base, technologies, demand type, links, and complementarities across artefacts and activities. Therefore, the boundaries of sectoral systems are not static. Nevertheless, this understanding does not picture the whole dynamics of the co-evolutionary perspective when it regards more than one dominant sector or how megatrends, such as technology convergence, are affecting the dynamics of sectoral systems.

In the literature, the same challenge comes with Diamond Model of Porter (1990) as well, that it lacks in explaining the case of interdependencies and links of more than one dominant sector. The third dimension of the Diamond Model is supportive and related sectors, which interact with the target sector both vertically and horizontally. Related sectors are those that are some customers, production factors, and/or technologies in common. In a broad view, Porter states that it is almost impossible to find only a single successful sector without strong and challenging supportive and related sectors, which is an important view for co-evolutionary perspective in the way that the distinction between supportive and related sectors helps to cover a large variety of interrelations and interdependencies between different sectors. Hacklin (2008, p.57) makes one of the noticeable explanations regarding SIS literature that technology (knowledge) convergence designates the development of unanticipated co-evolutionary spillover between previously unrelated and distinct knowledge-bases, giving the rise to the disruption of existing boundaries that determine sector specific-knowledge.

In general, in SIS approach the studies focus on feedback mechanisms when it comes to co-evolutionary perspective and lack of understanding of cross-sectoral dynamics. For instance, in one of the most recent studies, Malerba and Adams (2014) state that the co-evolutionary process that characterizes firms and other actors that establish the

fundamentals of SIS is often path-dependent and sector-specific. However, as they point out, analyzing the understanding of how specific processes of co-evolution occur with what kind of feedback mechanisms, became a challenge.

As aforementioned, while there are recent remarks about convergence (especially technology convergence) and its effects on sectoral boundaries and relatedly SIS, there are no studies regarding more than one dominant sector.

2.3. Industry Convergence

Recently, sectoral boundaries have become blurred very rapidly allowing firms to offer services in multiple markets in an environment that is affected by technology convergence (Papadakis, 2009, p.2, Kang and Oh, 2012). Therefore, the term “industry convergence” becomes striking each day. In this regard, the term “industry convergence” is also examined for determining the scope of this thesis. In addition, it is included in the literature review to determine the theoretical background of this thesis because of the relatedness of the research questions. However, there are a few mentions of “industry convergence” from the perspective of NIS and SIS approaches; there is no adequate contribution regarding both convergence literature and IS literature. Therefore, only remarks are shared below.

Convergence has been discussed mainly in connection with industries that are to a high degree science and technology-driven, even though it has been shaping industries throughout history. Curran and Leker (2011, p.259) define a pre-convergence status for industry convergence as a set of companies with different technology-bases, different application areas, and different target groups in different markets. Industry convergence evolves when scientific areas, technologies (mostly KETs), and/or markets are overlapping; boundaries are blurring.

Especially technology convergence has been a major force behind the development of new sectors. This is particularly true in the age of digitalization, where technical fields

are rarely separated. Therefore, when it comes to industry convergence ICT sector is the most given and most examined example. Moreover, recently not only technology but also the demand, market, and business sides are examined. For example, Borés et al. (2003) examining the ICT sector, state that sectors that are involved in the convergence process are converging towards a unified market, by which old markets change and transform into new ones.

In their research for analyzing dynamic patterns of industry convergence, Kim et al. (2015) demonstrate that industry convergence is increasing over time. While there are industry convergence analyses depending on technological data (scientific articles and/or patents like in Curran et al., 2010; Curran and Leker, 2011; Curran, 2013), Kim et al. (2015) discuss that market data is not examined in the literature. In this regard, in their study, they bring insight from firms and markets by analyzing newspaper articles with the co-occurrence method and web-crawling (text mining) technique. They come to a result that, industry convergence brings new dynamics across sectors, which causes transformation and creative destruction in their corresponding markets, value, and supply chains. They also note that industry convergence triggers restructuring in a traditional industry, which also leads to the emergence of a new industry; by giving an example from the smartphone industry. However, Kim et al. (2015) determine that industry convergence is not diffused to all existent sectors yet, and the rate of increase of convergence is rather greater within the industry than between industries over time; they also remark that the rate of diffusion is exponential. They determine dynamic patterns of industry convergence as evolutionary and stationary convergences and divergences; and stationary independence. These patterns depend on the degree of convergence between two industries increasing over time, and the degree reaches or remains in the area of convergence. In the case of evolutionary convergence, the two industries converge to a larger degree, and over time they transform a new sector, as well (Hacklin and Wallin, 2013; Kim et al., 2015). This result matches with the perspective presented in this thesis; which is determined as “cross-sectoral co-evolutionary” perspective.

Industry convergence can be also discussed from different viewpoints. In within-industry convergence, convergence occurs among sub-industries within a specific industry sector, as in the case of convergence between the automobile and electronics sub-industries within manufacturing (Hacklin, 2008; Kim et al., 2015). Some convergence happens between different industries, which can be defined as inter-industry convergence. In inter-industry convergence, two distinct industries overlap, as in the case of convergence between the manufacturing and the service industries (Hacklin, 2008; Kim et al., 2015, Geum, 2016). Which matches with the “cross-sectoral co-evolutionary” perspective as well. Figure 2.4 shows the visualization of industry convergence in the literature as aforementioned.

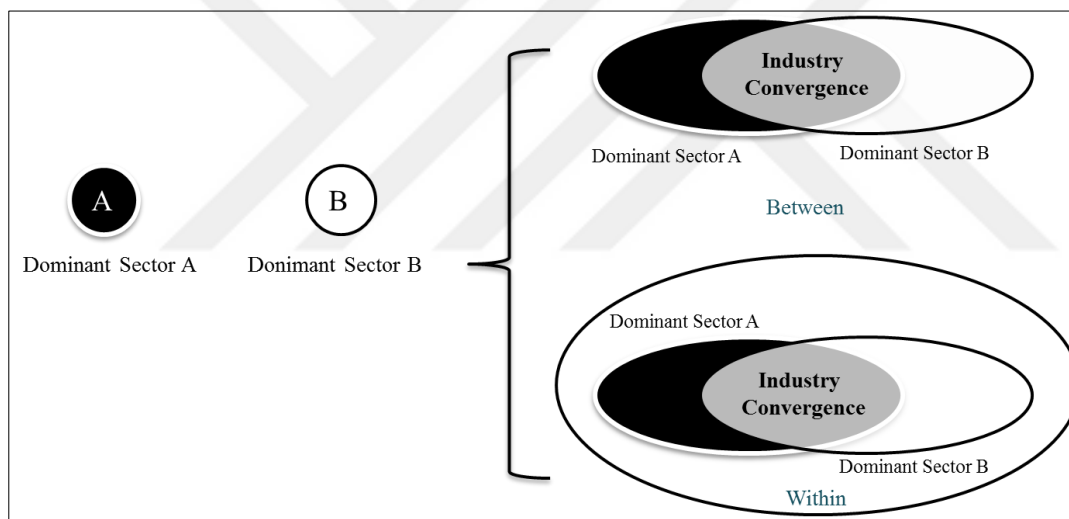


Figure 2.4. Visualization of Industry Convergence (Hacklin, 2008; Kim et al., 2015, p. 1735, Edited)

The process of innovation between sectors is discussed by several literature sources, however, it is not from the systemic perspective (Enkel and Gassmann 2010; Gassmann, et al., 2010, 2011; Bornkessel et al., 2016). By the examination of innovation across sectors in the convergence literature, the definition of “industry convergence” is given as the emergence of a new industry or sector consisting of firms

formerly active in different industries, leading to a blurring of boundaries between the industries (Bröring, 2005; Hacklin, 2008; Bornkessel et al., 2016).

The convergence process is examined by the sequential steps; science, technology, market, and industry. These steps are given as an idealized time series of events leading to a complete convergence of two distinct industries and/or sectors (Hacklin 2008; Curran et al., 2010). While the front end of the convergence process regarding science and technology convergences is detailed in many recent studies using mostly bibliometric data (Curran, 2010; Preschitschek et al., 2012), literature and methods on the examination of the consecutive steps of market and industry convergence are highly scarce (Bornkessel et al., 2016).

The aforementioned remarks suggest that, in order to meet the different needs of different industries, cross-sectoral convergence requires/triggers changes in the existing institutional structure or the creation of new ones. This brings a different approach to national and sectoral innovation systems (Zang, 2014, p.364); which are hitherto examined from scientific and technological sides for a large part of the literature. However, there is a need for a broad view covering the market and demand sides, as well. On the other hand, Malerba (2002a) emphasizes that the creation of new knowledge might be fulfilled in other sectors that are not part of the existing SIS and also can constitute external sources; where these additional sources are considered as related and/or supportive to the dominant sector.

From these perspectives, the point comes to front that it is highly related to the term itself being newly accommodated in the literature. However, the literature on the IS approach regarding industry convergence is almost absent, as well as, a methodology examining the dynamics of industry convergence within IS approaches. On the other hand, recent studies support the need to examine industry convergence within IS approaches. For example, Geum (2016) emphasizes that the current paradigm on innovation, especially the fast development of digital transformation and convergence,

proves the idea of innovation not occurring in isolation neither in a single sector while the notion of industry/sector is also changing.

For that matter, using the input from the literature review, a comparison table is prepared to understand the possible benefits of Cross-Sectoral Innovation System (CSIS) approach (Table 2.1). Nine criteria are used for the comparison of existing IS approaches and CSIS approach: (1) Definition/Main Unit of Analysis, (2) Boundaries of the Sector/Relation Between Different Sectors, (3) Focus on Technology Convergence, (4) (Cross-Sectoral) Co-Evolution Perspective, (5) Focus on Industry Convergence, (6) The Emergence of New Sectors, (7) Co-evolution of Internal and External Factors of Sectors, (8) Focus on Key Enabling Technologies (KETs) and (9) Interrelation Between IS Approaches.

From the comparison, it can be seen that CSIS approach brings a systemic perspective on the dynamic structure with interdependent constituents that co-evolve and transform each other in linear or non-linear ways that involves more than one dominant sector and/or systems. Specific focus is put on convergence (especially technology convergence), however, CSIS approach also examines the transformation of cross-sectoral dynamics. Therefore, a wider examination is integrated regarding the market, demand, regulative, and other macro-level sides; and not just micro-level sides. Moreover, since technology convergence is one of the essential forces behind the emergence of new sectors, sectoral boundaries, and sectoral dynamics resulting with key enabling technologies (KETs); there is a special focus on examining KETs as well, which is also covered in the perspective of demand-side innovation policies regarding IS approaches and convergence. It should be noted that, whether there would be a creation of new sectors as a result of or during the convergence, more focus is put on the changes in the dynamics of respective IS caused by convergence, and co-evolutionary process between examined sectors, rather than the new or established sector. Thus, it should be underlined that not only new sectors but the transformation of the dynamics of IS due to convergence effect is one of the main dimensions.



Table 2.1. Comparison of Current IS Approaches and CSIS Approach

Criteria / IS Approach	National Innovation System (NIS)	Regional Innovation System (RIS)	Sectoral Innovation System (SIS)	Complex Innovation System (CIS)	Cross-Sectoral Innovation System (CSIS)
Definition/Main Unit of Analysis	- A network composed of public and private sector institutions engaging in interactions to reproduce, import, modify and diffuse new technologies (Freeman, 1987, p.1; Soete et al., 2009, p.8). - Organized by components and interactions to interact in the production, diffusion, and use of new and economically useful knowledge (Lundvall, 1993). - Innovation milieu, national wide.	- Financial capacity, institutional learning, and productive culture, which facilitate systemic innovation at the regional level (Cooke et al., 2004). - Innovation milieu, regional wide.	- The specific clusters of the firms, technologies, and industries; and their knowledge flows that are involved in the creation and diffusion of new technologies (Malerba, 2002a, 2004). - Presents an understanding of the structure and boundaries of different sectors, actors in the focused sector, and their interactions. - Heterogeneity is key. - Sectoral dynamics, mostly firms.	- Has a dynamic structure with interdependent constituents that interact in complex and non-linear ways (Katz, 2006, 2016; Cooke, 2012). - Is composed of complex sub-systems. - Complex systems and sub-systems.	- Has a dynamic structure with interdependent constituents that co-evolve and transform each other in linear or non-linear ways. - Might evolve homogenously. - Constitutes of more than one dominant sector and/or systems. - Cross-sectoral dynamics, not only firms. - Transformation of sectoral dynamics.
Boundaries of the Sector/Relation Between Different Sectors	- National institutions-based approach. - Macro.	- Proximity and regional institutions based approach. - Macro or micro.	“Common knowledge-base” determines the sector. Firms also differ from each other regarding how the accumulation of knowledge takes place. - Mostly firm-based approach. - Analyzed in terms of knowledge flow between sectors. - Focus on one dominant sector with the related / supportive sector.	Systemic focus.	- One or more dominant sectors-based approach. - Dominant sectors converge and co-evolve.
Focus on Technology Convergence	Long waves of technological change.	No specific focus.	- No specific focus on analyzing the effect of convergence. Recent studies emphasize the importance and disruptive effect of convergence on sectors (Malerba and Adams, 2014). - No understanding of cross-sectoral convergence nor co-evolution (Li Y., 2013).	No specific focus.	- Specific focus. - One of the main dimensions. - Huge impact on the formation of new sectors and sectoral boundaries. - Rapid and disruptive technological change.

Table 2.1. (Cont'd)

Criteria / IS Approach	National Innovation System (NIS)	Regional Innovation System (RIS)	Sectoral Innovation System (SIS)	Complex Innovation System (CIS)	Cross-Sectoral Innovation System (CSIS)
Focus on (Cross-Sectoral) Co-Evolution Perspective	- No specific focus. - Learning and innovation are best understood as the outcome of an interaction. - Systemic in the sense that the different elements are interdependent and that interrelationships matter for innovation performance. (Lundvall, 2005).	- No specific focus. - Regional firm populations and private-sector innovation co-evolve with related public research activities in the respective region (Blakenberg and Buenstorf, 2016).	- Interdependencies and complementarities define the real boundaries of a sectoral system. It is a dynamic co-evolutionary process. (Malerba 1999, 2002a). - No understanding of cross-sectoral convergence nor co-evolution (Li Y., 2013).	No specific focus.	- Specific focus. - One of the main dimensions.
Focus on Industry Convergence	Long waves of technological change, vague explanation of the industrial change.	No specific focus.	- No specific focus. - Explained by the functions of the innovation system in which first of all, knowledge should be developed and then actors should come to change this knowledge into economic values, accordingly, the needed institutions will be built and the industry evolves.	No specific focus.	- Industry convergence is considered as one of the main dimensions since it mainly evolves from technology convergence and other convergence types. - The main focus is cross-sectoral convergence that consists of more than one dominant sector.
The Emergence of New Sectors	No specific focus.	No specific focus.	- No specific focus. - Same as "Industry Convergence" explained by functions of IS in which knowledge is developed. - Generally, developed -even slightly- sectors that have determinative dynamics are put in focus.	- No specific focus. - Can self-organize, i.e., its emergent properties may change its structure or create new structures.	- Technology and industry convergence play a crucial role. - Not only new sectors but the transformation/ convergence process is one of the main dimensions.

Table 2.1. (Cont'd)

Criteria / IS Approach	National Innovation System (NIS)	Regional Innovation System (RIS)	Sectoral Innovation System (SIS)	Complex Innovation System (CIS)	Cross-Sectoral Innovation System (CSIS)
Co-evolution of Internal and External Factors of Sectors	Institutional and regulation-based approach.	Institutional and regulation-based approach.	Actors, relations, and institutions in any sector co-evolve based on changes in the national and international actors (for example government), relations (for example political relations with other countries), and institutions (such as IPR laws). In other directions, the changes in the actors, relations, and institutions within the sector can alter similar components at national and even international levels.	No specific focus.	Examines the cross-sectoral, interdependent, and co-evolutionary relationships within the dominant sectors that converge together and can alter similar components in national, sectoral, regional, and even in wider global systems.
Focus on KETs	No specific focus.	No specific focus.	- No specific focus. - Technology convergence, new technologies, and their impacts are analyzed within sectors, not in the perspective of a cross-sectoral approach.	No specific focus.	KETs are considered as one of the main dimensions.
Interrelation Between IS Approaches	- Holistic approach for national development. - Can consist of regional and sectoral innovation system approaches. - Country-specific dynamics.	- Holistic approach for regional development. - Can involve a sectoral system approach for a specific region. - Country, region, and sector-specific dynamics.	- Holistic approach for sectoral development. - Sectoral and country-specific dynamics.	- Mostly examines regional/local innovation system approaches. - Complicated and complex systems.	- Holistic approach for more than one dominant sector. - Mainly based on SIS and functional dynamics approaches. However, focuses on cross-sectoral dynamics. - Country, region, and more than one sector-specific dynamics.

2.4. Demand-Side Innovation Policies, IS Approaches and Convergence

Edler (2007) suggests that the importance of demand-side innovation policies comes forward in terms of boosting demand for innovation, improving knowledge-creation and innovation processes, and/or improving the demand-creation process. Regarding the main research question of this thesis, that if there is a cross-sectoral co-evolution process based on technology convergence from the perspective of innovation system (IS) approaches, the relation between the technology-push and market-pull effects as in push-pull dynamic between technology convergence towards market convergence and the formation of industry convergence comes as a conspicuous process to be examined further. For that matter, the main remarks regarding demand-side innovation policies from the perspective of IS approaches and convergence are presented below.

Due to the high potentials of demand-side innovation policies, there are many applications within IS approaches, especially regarding NIS and SIS. Because of the nature of the demand-driven innovation being systemic, co-evolutionary, nonlinear, interactive, and iterative; and more recently cross-sectoral market-pull, and user-producer interaction (Edler 2007, Kaiser and Kripp, 2010; OECD 2011). While Malerba et al. (2007) argue that the successful introduction of cutting-edge technology in an industry depends on the existence of markets that old technology does not serve well, cases in which demand has a crucial effect in stimulating radical innovation have been central to the emergence of new technology. However, technology convergence is still a new process to be examined, it is still highly accepted that technological change has a crucial impact on demand and thus on innovation, and eventually market structure. Thus, studies concerning factors affecting the dynamics of industries support the idea of paying attention to the structure of demand and customer-side interest, as well as technology convergence. For example, in sectors such as open source software, communities are the source of incremental innovation and technological change, via co-invention, which also creates an interaction that blurs boundaries between supply and demand, triggers convergence between different technologies/sectors, also stimulates the learning process (Malerba, 2005).

Demand-side innovation policies are playing a critical role in terms of public procurement and standardization. Particularly public procurement for innovation and the application of large and mission-oriented technology procurement policies date back to the 1970s (Mowery and Rosenberg, 1979; Geroski, 1990; Edler et al., 2009). However, recently these practices have been implemented in industrial policies to support specific sectors and achieve specific objectives within mission-oriented R&D policies.

One of the points highlighted in the literature is that the supply of new technologies is triggered by demand and the economic value added is based on the interaction between supply and demand. Thus, the application of "technology-push" and "market-pull" theories of innovation come forward as one of the most important subjects highlighted in innovation literature in terms of demand-side policies (Mowery and Rosenberg, 1979; Martin, 1994; Nemet, 2009; OECD, 2011). This is also related to the main research question of this thesis particularly, regarding the interactive process between "technology-push" and "market-pull", and its impact on cross-sectoral convergence. Especially, Malerba (2005) demonstrates the significance of sector-specific structures whether demand is homogenous or heterogeneous; or sectors being science-driven or standards-driven, etc. These factors are also very crucial for cross-sectoral convergence, whether if it leads to industry convergence or not; or how it changes the dynamics of an innovation system from the firm side, market side, research side, and/or regulation side, etc.

In demand-side innovation policies, technology-push suggests that technology R&D is dominant in the development of new products, and market research is not usually necessary. Ryan (2013) states that a company can develop, manufacture, and commercialize innovative technology without market orientation just based on technology trends. For example, touch screen technology was developed as a result of research in the middle of the 1960s, later it has become a sub-technological area of ICT and advanced materials. In the 1980s, HP launched a touch screen computer. In 1993, Apple developed the first touchscreen PDA. Soon after, in 1996, PALM began

producing the pilot series. Currently, touch screen technology is quite common with smartphones and tablets, and on every surface as a converging technology.

On the other hand, market-pull demand-side innovation policies suggest that technology and innovation are developed towards the needs of the market. Potential target user-base and market research are important, and essential for the products and the technology that are being developed. Ryan (2013) states that in such policies, incentives for user-oriented experience are often highlighted in existing products.

For example; in the 1980s, photography cameras, which took unlimited photographs and showed them instantly, rose in demand. This supply in the market triggered electronics companies and led to the development of digital cameras. However, market supply has also improved the photo processing software. In 1981, SONY launched the first digital camera called Mavica to the market and it is a revolutionary feature in the product photography industry. Then in 1986, KODAK developed the first professional digital camera system and selected the newspaper photographers as the target user-base. Eight years later, Apple targeted a wider user-base and has developed a photo camera called QuickTake 100 that can be used interactively with personal computers. Following this development, KODAK, SONY, and CASIO products were introduced to the market in the same direction. Today, in the same way, market demand develops towards a product that uses social sharing and instant printing. Although the basic technology that was required has been greatly improved and the demand has been exceeded, with the widespread use of mobile technologies and smart devices, the digital camera industry has become a sector with a smaller target user-base; that is again mostly serving professionals. As can be seen, demand triggers innovation and pulls new technologies to the market.

Similar to the aforementioned “technology-push” and “market-pull” demand-side innovation policies, von Hippel (2005) and Allman et al. (2011) suggest that there are two types of links between demand and innovation. The first link is where demand responds to and triggers innovation, thus plays a crucial role in promoting innovation, and the second link is where demand is the direct source of innovation. In the first link,

when innovation is developed, demand can grow in the direction of utilizing the innovation. In the case of the second link, the public or private sector needs to be directly targeted; so there is demand in the lead role for the development of innovation.

Although offering an understanding of how inventions happen, there are also limitations in both technology-push and market-pull demand-side innovation policies. Nemet (2009) emphasizes that demand-side innovation policies that are backed by the technology-push side disregard the market for the innovation; whereas demand-side innovation policies that are backed by the market-pull side disregard procurement conditions. This means that separately they offer a one-sided perspective besides without bringing systemic, interactive, and holistic approaches together, disregarding the nature of innovation. Therefore, the interaction between the two approaches is also one of the most investigated subjects in the literature. Mowery and Rosenberg (1979) state that both approaches need to exist simultaneously. Similarly, Freeman's (1974) research on outputs of forty innovations shows that the success of the creation of innovation rises in environments where the technological and market opportunities trigger each other.

One of the important dimensions of technology-push based innovation is standards and standardization processes. In the literature, there are various analyzes of how standards affect innovation. For example, Blind's (2009) study on standardization as a catalyst for innovation matches standards with research activities and influenced innovation-focused public procurement policies. According to this study, the integration of patents into standards expands and accelerates the spread of technological know-how. On the other hand, standards may be binding in terms of innovation and entrepreneurship. It is emphasized that the timing of the standards is very important for the product diversity and the private sector to be locked into internal standards; as well as the formation of the market and emergence of new sectors, rather triggering convergence.

The role of demand is also one of the subjects that are evaluated in terms of competitiveness. Demand in the national market supports firms to create competitive

advantage, which is one of the dimensions in The Diamond Model developed by Porter (1990). In this context, the concept of "lead market" stands out in the literature and applications (Edler et al., 2009; OECD, 2011). In the literature, the prior conditions to determine which market will be the lead emerge as the early potential buyer signals towards innovative products, the high finance to the initial cost of innovation, the demanding critical mass, the national (and international) priority of the problem to be solved in the market, technological and production capacity in the entire value-added chain (Georgiou, 2007; Edler et al., 2009; OECD, 2011).

Since the focal point of this thesis is the cross-sectoral perspective, it is also necessary to discuss the effect of demand-side innovation policies on sector-specific innovation dynamics, as well as industry convergence. For this reason, technology-push and market-pull demand-side innovation policies are evaluated in the context of complementary literature. Other applications of demand-based innovation policies, such as standardization, public procurement, tax incentives, tariff applications, and regulation, etc. are referred to as examples in the literature.

One of the most frequently discussed issues in the literature is the development of systemic innovation policies in order to improve the organization of knowledge flows between R&D constructors, producers, users, consumers, and other actors affected by innovation, in order to determine priorities and market needs (von Hippel, 2005). This issue is also addressed under SIS approach because sectors vary significantly in terms of innovation dynamics and their market structure (Malerba, 2002a, 2005; Malerba et al., 2007). For example, in the energy sector, guaranteed tariff applications especially for use of renewable resources and electricity generation are emphasized, while tax incentive reductions in the automotive sector and standardization policies in the ICT sector are more on the agenda (OECD, 2011).

From the perspective of industry convergence, Curran (2013) reviews the arguments in the literature that are integrating technology-push and market-pull process, as input-side and output-side convergence. While fast development of technology enables firms to fulfill the supply with new or enhanced products, new dynamics by end-users and

customer behavior may lead to demand-driven output-side convergence. It is stated that the degree to which would happen is largely dependent on the triggers and drivers behind the convergence. Because, changes in customer demands (from other organizations to individuals) or even in regulations and standards can be at least equally important factors, which are also very crucial dynamics of NIS and SIS.

For instance, regulations, which can be considered as in the middle between input- and output-side, are seen cause of significant impacts. Giving an example from “Functional Foods”, Curran (2013) states that the question of whether a product is viewed as a food ingredient, a dietary supplement, or a drug might change the demand and commercial viability of a compound completely. It is also argued that industry convergence only occurs where input- and output-side convergence takes place. Where this leads to substitution of previous sectoral segments, innovation is considered interrelated to the trends of convergence. On the other hand, Bezzina and Sanchez (2005) state that regulations require a transition to a cross-product, cross-platform, and cross-sectional licensing. Particularly, the changes in the dynamics of the sector require a detailed examination of the transformation of the systems, as well as the new SIS. Moreover, while regarding the dynamic interaction among the scientific, technological, political, and market areas, it is also important to consider the difference in speed of changes each of them has. For instance, technological innovation is more dynamic than the competitive dynamic of the market; which affects the dynamics of convergence as well; and the adequacy and stability of public policy and the legal framework generally come after; even in the situations where they should be proactive.

As a result, as seen in the examples given before, demand-side innovation policies can be both technology-push and market-pull, influenced by both the development of new technology and the rapid development of existing technology. Most importantly especially, regarding the auxiliary research question of this thesis considering the formation of KETs based on the conceptualization of the cross-sectoral co-evolution; the interaction between technology-push and market-pull comes forward. This interaction triggers the emergence of KETs, which also affects both the formation of the current market and the development of new markets; and eventually the dynamics

of the existing sector as well as the new sector. To elaborate on the importance of KETs, breakthroughs in technology can be given as examples. For example, the level of technology that many people can use at the same time, that even small firms have become competing in areas that otherwise could not compete, has upsurged by the convergence of communication technologies, the internet, and networks. From this point, they are also called "disruptive" (in a positive sense)⁴ technologies because KETs cause entirely radical changes. Technologies that can be used for general purposes, such as ICTs, are depicted as "destructive" because of the speed of self-renewal and the radical transformation impact on other technologies, and sectors (MGI, 2013). KETs are confronted as a horizontal area due to their ability to trigger developments in a wide variety of areas from automotive to defense. For this reason, the progress in the KETs is affecting all sectors by creating a multiplier effect.

Although a significant portion of the products and services of the future are not yet known, it is stated that the most important driving force behind their development will be the KETs (MGI, 2013). KETs are keen to trigger the learning process and, at the same time, are engaged in high-level R&D, rapid innovation cycles, high capital expenditure, and highly qualified employment. KETs are also multi and interdisciplinary, and converging in nature, that intersects with many technology areas. Moreover, they provide dual-use purposes between sectors providing wider research areas from other sectors other areas. For this reason, they have a very important place in the cross-sectoral approach and industry convergence. For example, micro and nanoelectronics including semiconductors are considered to be KETs and are seen as the basis for all products and services in the automotive, transportation, aviation, and aerospace sectors which also triggers a cross-sectoral approach. Therefore, KETs are also examined in the analysis as they are considered as one of the main dimensions of the cross-sectoral approach under the scope of this thesis.

⁴ In the scope of this thesis, only the positive meaning of "disruptive" is covered; which can result in radical advancements and breakthroughs.

2.5. Key Findings of the Literature Review

National, regional, sectoral and complex IS approaches are used for mapping and explaining interactions between actors, mainly firms and organizations that generate knowledge, co-create and innovate. It is observed that while current IS literature focuses on technological change through a technological evolution analysis, there is little research that treats convergence as the central theme while analyzing more than one dominant sector, their transformation process, and co-evolutionary cross-sectoral dynamics. For instance, as shown in Figure 2.2 above, SIS approach concerns the dynamics of one dominant sector and pays attention to the links, complementarities, and interdependencies of related sectors.

The findings of the literature review based on technology convergence, cross-sectoral co-evolution and industry convergence from the perspectives of IS approaches constitute basic benefits of CSIS approach; which are also summarized and compared in Table 2.1, above. Since, convergence is emerging as one of the most significant and disruptive developments where the dominant sector in the new economy is created by the merge of two or more sectors, two distinct structures (technologies, systems, sectors, etc.), the need for a different systemic approach and a research methodology is increasing rapidly in an inadmissible way.

Therefore, first and most importantly, CSIS approach integrates convergence and IS approaches altogether from the co-evolutionary perspective of more than one dominant sector and/or system. While in the existing SIS approach the focus is put on one dominant sector, and other sectors are considered as supportive and/or related sectors; CSIS brings a complementary perspective by doing so. It also brings a wider examination of scientific, technology, market sides of sectors, as well as demand-side innovation policies while regarding them as triggers and drivers of convergence, and puts special focus on the transformation of the dynamics of innovation systems. Interactively, cross-sectoral approaches based on convergence and demand-side innovation policies lead to the emergence of KETs, while also the emergence of the KETs triggers convergence, and eventually the formation of new sectors, sectoral

boundaries, and sectoral dynamics. Therefore, CSIS approach naturally embraces KETs as one of the main dimensions as well.

Recently, the threats and opportunities associated with technological convergence are discussed due to their strategic impact and policy significance for IS approaches, particularly NIS, in the “R&D Management Conference” held in the UK, in 2016. One of the important outcomes of the aforementioned Conference is that there is a lack of coherent frameworks and practical methods for understanding and dealing with disruptive effects of technology convergence, in particular, in the perspective of IS approaches. Therefore, contributions to both concept and practice that would address these challenges are stated as crucial for further development.

To summarize, current IS approaches do not analyze directly related and/or supportive sectors as one of the main components of the system. Therefore, the main finding of the literature review is that there are no satisfactory methodology studies, nor a holistic approach regarding technology convergence, cross-sectoral co-evolution, and industry convergence in the related literature, to examine the transformation of sectors, sectoral dynamics, and innovation systems, as well as the possible formation of new sectors with new dynamics as a result.

Briefly, CSIS approach as a concept intends to examine the cross-sectoral, interdependent, and co-evolutionary relationships within more than one dominant sector that converge together and can alter similar components in national, sectoral, regional, and even in wider global innovation systems. In that sense, CSIS approach can be defined as a framework of cross-sectoral distinct institutions whose interactions contribute jointly to the innovation process of more than one dominant sector affected by the convergence, and even used to observe the emergence of new sectors.

As a result, the findings of the literature review are used to develop the methodology for analyzing cross-sectoral dynamics while integrating convergence and contributed to the formulation of the main concept of CSIS approach.

CHAPTER 3

DESCRIPTIVE STUDY OF CROSS-SECTORAL DYNAMICS

This chapter is conducted for a better understanding of the sectors that are transforming due to the effect of convergence (especially technology convergence), and that show cross-sectoral and co-evolutionary aspects. For this matter, the focus is put on **“converging industries”** and **“industry convergence”** terms. This way, this chapter also aims to discuss the cases in the convergence literature to highlight the gaps regarding systemic approaches. The findings of this chapter are used for the formulation of the main concept of CSIS approach. More importantly, the results of the descriptive study are also used as inputs for the selection of the sectors for the case study, presented in Chapter 5.

This chapter is composed of two parts. Firstly, bibliometric co-occurrence analysis is conducted on the scientific publication data on SCOPUS Database between the years 2007-2017 based on the keywords “converging industries” and “industry convergence”. Findings of the descriptive research are presented, so to say, as another literature review regarding the scope of “converging industries” and “industry convergence”, which are both newly developing research areas within both convergence literature and innovation systems (IS) literature. Secondly, to see converging sectors independent from the boundaries and externalities that cause convergence, a “Cross-Sectoral Matching Analysis of Sectoral Dynamics” is made using the results of “R&D Based Solutions for Sectoral Problems Study” which considers fifteen sectors separately (Saraçoğlu, 2014, TÜBİTAK data).

There is no doubt that with the increased digital transformation, more sectors, even traditional ones, are transforming rapidly. For instance, a recent OECD (2019) study presents conceptual research regarding the impacts of the digital transformation on

innovation across sectors, taking into consideration of three sectors; agri-food (digital agriculture); retail, and automotive. On the other hand, previous works show how the ICT sector and other sectors are converging and creating new sectors, how ICTs become a key production and differentiation factor in almost all sectors.

From the noteworthy findings of this chapter, besides horizontal and rather developed sectors (and converging technologies) such as nanotechnology and biotechnology or more recently synthetic biology, the literature demonstrates that there are converging industries such as; functional foods (food industry + life sciences (and cosmetics); packaging sector (pulp and paper industry + ICT); camera phones sector (telecom industry + camera technology); intelligent/smart buildings sector (construction technology + ICT). In this manner, Figure 3.1 is prepared to show an extract of examples of converging industries, as well as related KETs.

The figure also demonstrates some of the examples of converging dominant actors via acquisition, or strategic cross-sectoral collaborations and investments. As can be seen, besides Functional Foods, FinTech, New Media, Personalized Medicine, Automotive and ICT sectors; with Manufacturing Sector in third, display one of the emerging potentials for converging industries, which are in rapid transformation.

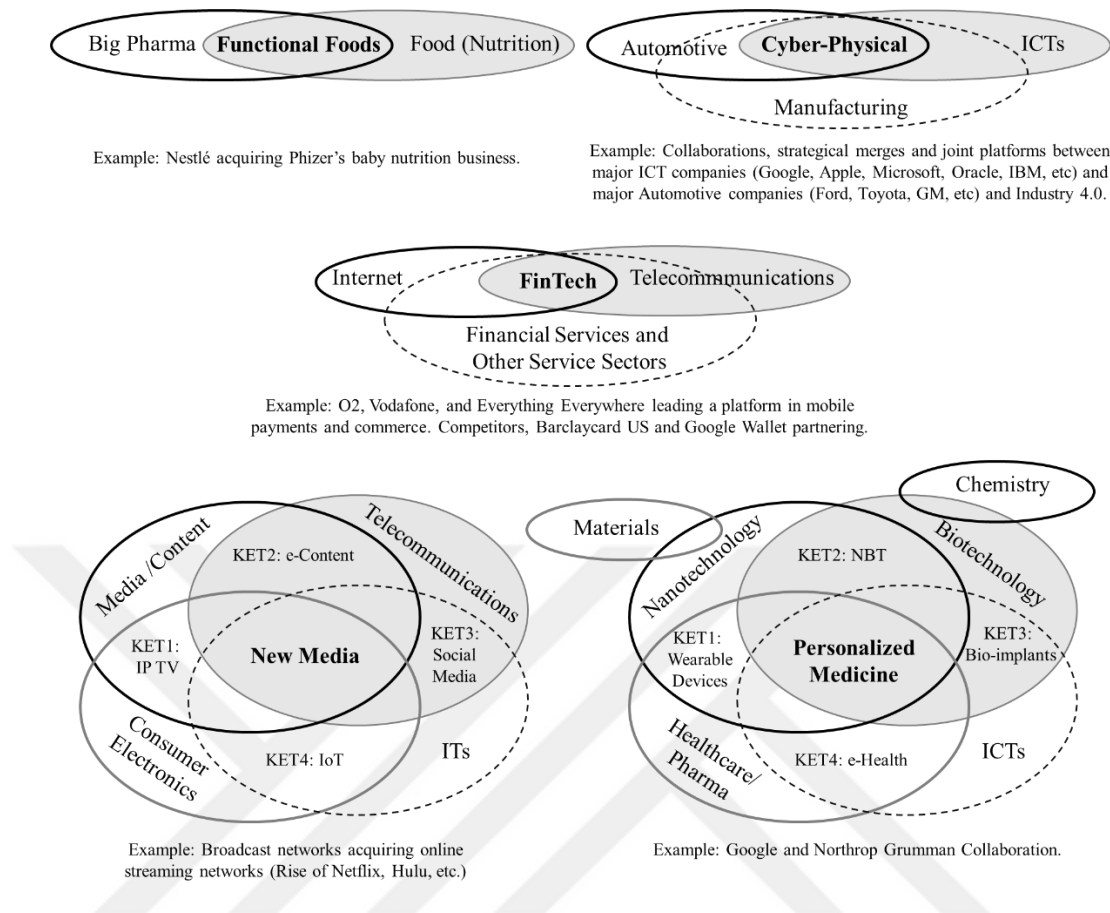


Figure 3.1. Examples of Converging Industries and Related KETs

3.1. Descriptive Research of Cross-Sectoral Dynamics

For this section, the terms “converging industries” and industry convergence” are used to understand the general approach to cross-sectoral dynamics better. This study is conducted as complementary to “Theoretical Background”, which is presented in Chapter 2. Seemingly, both terms are covering the same scope, while there are minor differences in determination. Regarding the general approach to **converging industries**, there are two processes defined by Bornkessel et al. (2016). One of them is the outside-in process that encompasses the integration of resources and competencies from other industry sectors; such as a company being a licensee. The other is the inside-out process, which focuses on the externalization of assets towards other industry sectors; such as a company being a licensor. These two processes eventually lead to a process of convergence.

In the case of **industry convergence**, Hacklin et al., (2009) define the general approach as technologies and applications from distinct domains being integrated into novel technological and applicational designs, resulting in original value-creating grounds of principal sectors or industries merging. Such impacts of industry convergence can be wide, causing completely new competitive patterns, as previously recognized industry boundaries become blurred, or non-existent.

As a method, bibliometric co-occurrence analysis based on scientific publication data on SCOPUS Database between the years 2007-2017 using the terms of “converging industries” and “industry convergence” is made. Using data from SCOPUS Database based on author keywords, and co-authorship analysis based on countries, an overlay visualization is prepared using VOSviewer. Data between the years 2007-2017 is retrieved, but the literature seems to become prominent starting from 2012. As an analysis method, LinLog/modularity is preferred. In the co-occurrence mapping analysis with the text mining method, 5.693 keywords are analyzed and 285 met the threshold with a minimum number of co-occurrence of keywords taken as five.

There are a couple of limitations regarding this analysis. First of all, all scientific data retrieved from SCOPUS Database; therefore, retrieval limitations of the aforementioned database are considered while analyzing the data. In addition, duplications are eliminated for all data; text clustering and text mining methods are conducted via VOSviewer. Bibliometric co-occurrence analysis based on scientific publication data on SCOPUS Database between the years 2007-2017 using the terms of “converging industries” and “industry convergence” show mainly three findings, elaborated below.

Firstly, Figure 3.2 presents seven clusters based on publication data. As seen from the figure, technology convergence is the most frequent term as well as digital convergence. Moreover, prominent sectors are seen as; ICT sector, functional food, health, food industry, pharmaceutical industry, biotechnology, nanotechnology, gene

therapy, cell and tissue technologies, vehicles (including automotive), energy, chemicals, agriculture, and space technology.

Secondly, Figure 3.3 presents an overlay visualization mapping of co-occurrence of terms weighted by average publication year, scaled between the years 2008-2016. Technology convergence is both weighted and the most recent term, following by cell, tissue, gene therapy, and vehicles technology. ICTs, nanotechnology, bioeconomy, health, energy, and agriculture also come forward. Digital convergence and related terms seem to be older. However, in the same yearly scale of digital convergence, the demand-side innovation related terms; such as consumer/user-driven, and business models, can be seen.

Lastly, Figure 3.4 shows co-authorship analysis based on countries and timeline-based overlay visualization mapping between the years 2007-2017. Twenty-six countries and nine clusters are seen. Weighted by average publication year and as the analysis method, LinLog/modularity is used. As a result, South Korea, USA, Germany, UK, and China are the five prominent countries in the context of “converging industries” and “industry convergence”. South Korea is strongly linked with USA, Germany, Japan, and Nepal. Brazil and Taiwan are separated but also significant clusters based on the timeline-based mapping.

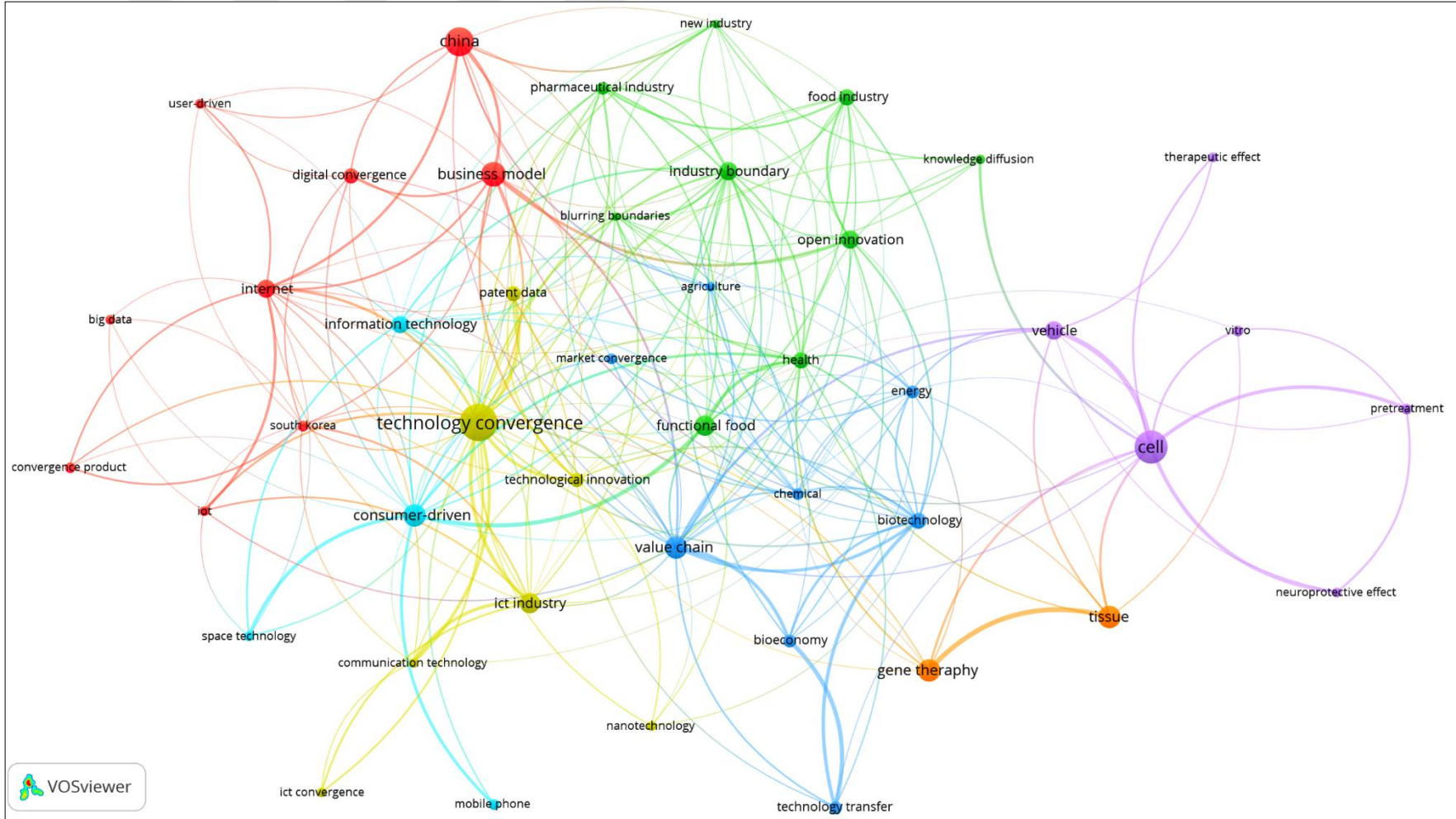


Figure 3.2. Co-occurrence Mapping of Descriptive Research, 2007-2017



Figure 3.3. Overlay Visualization for Co-occurrence Mapping of Descriptive Research, 2007-2017

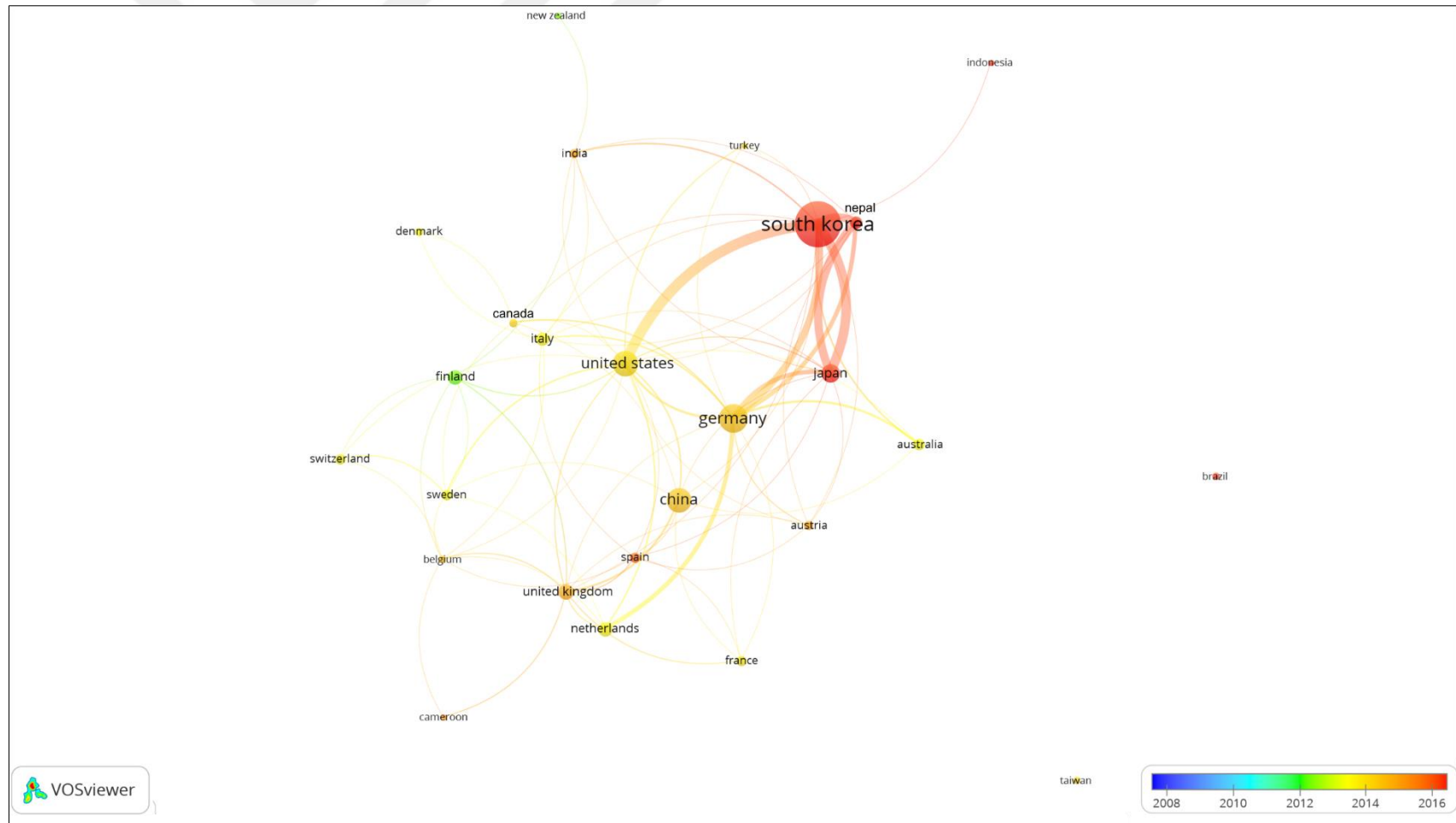


Figure 3.4. Overlay Visualization of Co-Authorship Mapping of Countries from Descriptive Research, 2007-2017

3.1.1. Descriptive Research Outputs

As aforementioned in Chapter 2 “Theoretical Background”, according to the Harvard Business Review (2012), convergence is considered as one of the major trends where the dominant sector in the new economy is formed by the convergence of two or more sectors, while creating new business models, value chains, partnerships across sectors, dynamics of innovation systems, and revenue streams, etc. Although the literature still focuses more on technology convergence, the disruptive effects of the convergence trend lead to the emergence of the term industry convergence. Therefore, there are several sources in the literature on industry convergence that give a solid perspective on the trend of convergence of two or more sectors (Gerum et al., 2004; Bröring, 2005; Bröring et al., 2006; Hacklin et al., 2009; Curran et al. 2010; DETECON Consulting, 2011; Sharp, 2011; Curran and Leker, 2011; Kang and Oh, 2012; Curran, 2013; Li et al., 2013; Kim et al., 2015; Bornkessel et al., 2016; Barnatt, 2016; OECD, 2014b, 2016, 2018, 2019).

In those perspectives, the method of analyses mostly includes using secondary data from interviews, or empirical data, and patent data. ICT sector comes front as the most examined sector, as well as impacts of the digital transformation on innovation across sectors (energy, health, agri-food (which is also a converging industry per se), automotive, retail, construction, finance, etc.). Besides, there is a focus on horizontal and rather developed sectors (and converging technologies) such as nanotechnology and biotechnology or more recently synthetic biology. As well as their converging industries such as nanobiotechs or synbiotechs. Moreover, the research includes bioeconomy, functional foods, personal medicine, biomedical devices, new media, and the service sector. For example, the development of fintech sector is in itself very interesting causing many other derivative convergences; such as insurtech, regtech sectors. There is also a big mash-up for digital commerce convergence, where traditional consumer sectors transform into online and mobile platforms while consumer behavior and demand are also changing (McCracken, 2012).

McCracken (2012) also reports that especially each of retail, online service, mobile service, media, payments and financial service businesses is moving into other traditional sectors. For instance, Tesco Bank was a retailer and became a dominant actor in financial services, and Virgin was a music brand that now has its hands in many domains across retail, travel, online and mobile services, media, payments, and most recently, retail banking.

Moreover, “exponentially growing” technologies, which are also called disruptive or key enabling technologies (KETs); such as 3D printing, sensors, AI, robotics, drones, and nanotechnology, are mostly key to the transformation and convergence of sectors (Deloitte, 2014). KETs also represent a huge potential to become new sectors themselves. For example, the trend of Industry 4.0 shows that the widespread adoption by the manufacturing sector and traditional production operations of the ICT sector is increasingly blurring the boundaries between the real world and the virtual world in what is developing as cyber-physical systems (Deloitte, 2014) causing the development of a new sector combining traditional ones as well as knowledge-driven ones. In that regard, a few examples also can be given from biopharma, nutrition products, health care, and energy, where technologies and distinct knowledge-bases are changing and converging. Perhaps the most dramatic example of such convergence is taking place in the thriving of telecommunications, information technology, media, and entertainment (Hacklin et al., 2013).

DETECON Consulting (2011) presents how the ICT sector is converging with other sectors and gives examples of cross-sectoral convergence through the 2030s. It is stated that ICTs drive innovation in all areas of life, while the IoT is becoming more effective in daily life. ICTs have become a key production and differentiation factor in almost all sectors, while data, IP, and platform-centric business models transform the economy. Energy, automotive, and health sectors are the three dominant sectors in the convergence of ICTs that are particularly examined. In this regard, the focus is put on digital transformation, such as medical being entirely digital from pills to implanted microchips; or other connected body parts. However, examinations also present how market size and development, market drivers are changing by cross-sectoral

convergence while also combining several sectors such as energy, automotive, and ICT sectors, resulting in the development of cross-sectoral products and applications such as virtual power plants, e-mobility, and vehicle-to-grid. In another example for automotive and ICT cross-sectoral convergence shows innovation applications such as full access to all kinds of real time information, multi-media and social network on the move as digitally connected cars.

DETECON (2011) also presents how vertical disintegration becomes horizontal integration in the context of cross-sectoral convergence. Standardization and opening of value chain interfaces drive vertical disintegration. Horizontal integration emerges due to proprietary cross-sectoral interfaces. In the 2010s vertical disintegration is dominant whereas it is expected that horizontal integration will be dominant in the 2030s in the cross-sectoral context. Moreover, it is stated that the dynamics of ICT-convergence will expand to industry convergence and create a new industry structure, such as business as a service, infrastructure as a service, and consumer-ICT mediation. DETECON (2011) suggests that in the 2010s the economic value of the convergence was already exceeding four trillion dollars, whereas in the 2030s the economic value of ICT-enabled industry convergence with automotive (transport and mobility), health and environment, and energy can not yet be calculated.

In addition to the disruptive impact of the ICT sector, there is also a huge focus on functional foods in the literature of converging industries and industry convergence. For instance, Bröring (2005) examines different project types, innovation strategies, and front-end decision-making approaches in the converging industry of Nutraceuticals and Functional Foods (NFF), which is developing by the Pharmaceutical and the Food sectors, which are mainly very different sectors. Consequently, Bröring et al. (2006) present further empirical findings based on primary data collected from R&D projects of nutraceutical cluster. NFF convergence shows that not only technologies blur, but there is also a convergence of demand structures: consumers try to satisfy different needs in one transaction.

Hacklin et al. (2009) examine convergence between industries, with a focus on firms active in such intersectional environments, especially regarding ICTs and nano- and biotechnology (NBT); underlining the cumulative market value for converging info-, bio-, and nanotechnologies. On the other hand, Hacklin et al. (2009) also depict examples of convergent development trends between sectors. In particular, emerging scientific advances in the intersection of microelectronics, material design, molecular biology, as well as complex chemistry result in nanoscale developments, which trigger the transformation of sectoral dynamics as well as the formation of new sectors. They suggest that in the case of ICTs, in which convergence is already very common, a high degree of network effects is relevant. However, regarding NBT, convergence emerges around scientific advances. On the other hand, even in the case of different demands knowledge and technology-bases of both sectors converge while creating a different market-base. Specifically, alliances can be observed reaching beyond previously established sectoral boundaries. Examples of such trends can be seen in internet companies taking over previously established media giants, as well as in incumbent phone carriers distancing themselves from their core telecom business with a succession of internet-related acquisitions (Wirtz, 2001).

On the other hand, in the matter of NBTs, Hacklin et al. (2009) do not regard nanotechnology as an industry per se like some others such as OECD (2014b). They define nanotechnology as the convergence of traditional knowledge-bases of chemistry, physics, mathematics, biology, and engineering sciences and as a phenomenon of existing industries, as they convergence on an atomic scale. As OECD (2014b) states nanotechnology (encompassing both nanosciences and nanotechnologies) has been identified by some as a cornerstone of various visions of converging technologies. However, recent documents define nanotechnology as both an industry and a general-purpose technology, and also still a scientific area that is very closely constrained with applicational areas (Vault, 2019; Nanoindustries, 2019; USA National Nanotechnology Initiative, 2019; Nanotechnology Market Outlook 2025). For instance, according to Vault (2019) nanotechnology can be viewed as an industry if the focus is kept on activities that advance the knowledge of nanoscale materials and how they can be used. There are also nanotechnology-inspired grand

challenges such as for Future Computing, which shows how nanotechnology is converging materials, ICTs, and human-computer interaction technologies while also causing separated sectors to intersect more and more. According to Nanotechnology Market Outlook 2025, the term nanotechnology describes a range of technologies performed on a nanometer scale with widespread applications in various industries, and it is by nature converging. Nanotechnology carries a significant impact and serves as a revolutionary and beneficial general purpose technology across various industrial domains and, including communication, medicine, transportation, agriculture, energy, materials & manufacturing, consumer products, and households; resulting in the creation of KETs and the formation of new sectors. In both views, nanotechnology has a converging effect both as a technology and as an industry, which actually does not come across with the perspective and findings of Hacklin et al. (2009).

Moreover, Sharp (2011) focuses mostly on science convergence regarding life sciences, engineering, and physical science. Convergence is defined as a blueprint of innovation and determined as a co-evolutionary process. On the other hand, it is also emphasized, how the impact of convergence is not only limited to sciences but also in a broad array of sectors from health care to energy, food, climate, and water. After defining two major advances in life sciences as revolutionary, which are molecular biology and genomics respectively, Sharp (2011) emphasizes convergence as the third revolution that brings interdisciplinary approaches combined. As aforementioned, even though the focus is on science convergence, examples of convergence revolution in biomedical research, which brings different and interdisciplinary knowledge-bases together, give specific perspectives on cross-sectoral convergence as well. Such as; computational biology, nanotechnology for targeted drug delivery, bacterial plasticity for tumor detection and drug delivery, CTC-chip for detecting cancer metastases. Cross-sectoral convergence implies broad transformation from knowledge-bases to technology-bases and market-bases, respectively.

While Curran et al. (2010) and Curran and Lekker (2011) have analyzed the patterns of industry convergence from the technological perspective using patent information provides important information about how industry converges at the technological

level, it does not provide any market-level evidence of industry convergence. Furthermore, those studies only covered a few industries, such as smartphones, functional foods, and intelligent buildings. On the other hand, Curran (2013) gives many examples of converging industries. As usual, one of the primary examples of converging industries is the area of information technologies, consumer electronics, and telecommunication (ICTs). Curran (2013) states that KETs may not always have decisive effects, but especially when a combination of new technologies arises, it can substantially alter products, manufacturing processes, or even whole sectors. Especially in science and technology-driven industries like the telecommunication or the pharmaceutical sectors, a convergence of technologies will often be a decisive part of industry convergence. Curran (2013) also analyses the convergence of food and pharmaceutical sectors in the area of NFF depending on the analysis model of ICT convergence, which is based mainly on scientific and patent analyses, and asks if patterns of convergence are generalizable for cross-sectoral boundaries.

Some other converging industries that are mentioned by Curran (2013) are the IT and electronics industry with other industries that often employed example is the area of intelligent buildings (or smart homes). Furthermore, the chemical sector particularly with biotechnology, pharmaceuticals, advanced materials, manufacturing, and agriculture sectors; the pharmaceutical sector being affected by developments involving nanotechnology, biotechnology, information technology, and cognitive science but also food sectors. Finally, yet importantly, the convergence of the service sector and other sectors is also mentioned, such as traditional sectors (health care) with the finance sector (insurance, banking, etc.).

Kang and Oh (2012) also emphasize that convergence is a megatrend across every technology and every product globally in the current economies. One of the examples given is the convergence of nanotechnology, biotechnology, information technology, and cognitive sciences. Another example is bioinformatics converging from information technology and biotechnology. On the other hand, the convergence of the geospatial sector is also mentioned. It is stated that while before remote sensing, GIS, CAD, and navigation were different vertical markets served by different technological

providers, currently these namely geo-enabled technologies are stated as converging technologies, and their respective markets have become horizontally integrated. The example of the medical devices sector which is the convergence of microelectronics, nanotechnology, machinery manufacturing (micromachining like lab-on-chip), biotechnology and advanced materials (biomaterials), and tissue engineering is also mentioned (Wilkinson, 2005; Kang and Oh, 2012).

Moreover, in their research Kim et al. (2015) analyzed all sectors in the USA, spanning 24 years from 1989 to 2012, where the data cover about 2 million articles, including around 13,000 companies from all sectors; and they found that overall industry convergence is increasing over time. Kim et al. (2015) also state that industry convergence triggers restructuring in traditional industries, and leads to the emergence of a new industry. In their study, the patterns of industrial distance demonstrate that some industries show a higher probability of converging with each other. For instance, agricultural, forestry, and fishing, manufacturing, transportation, communications, electric, gas, and sanitary services, wholesale trade, services, and public administration became closer within industry convergence process. Therefore, they emphasize that industry convergence triggers restructuring in traditional industries, and leads to the emergence of new industries.

Bornkessel et al. (2016) define convergence processes that are based on the activity of distinct sectors showing cross-sectoral collaborations. They also focus on functional foods and give examples of collaborations of companies from the food (Nestlé/Danone) and pharmaceutical (Martek/Bayer Health Care) sectors. Their analysis shows that food companies are more active in cross-sectoral collaborations than pharmaceutical companies are. Furthermore, they show that the emergence of a new industry consisting of firms formerly active in different industries, leading to a blurring of boundaries between the industries.

Another interesting case of industry convergence of media (also encompassing the converged industries of computing and telecommunications), medicine, and manufacturing is mentioned by Barnatt (2016); that while these three distant domains

started to merge in the 2010s, by around 2030 they will have very significant overlap because they share increasingly organic modes of operation at the same level of scale. However, it is also driven by an increasingly common reliance on digitization. While the current media sector is already essentially digital; medicine and manufacturing are also going digital. Medical is stated in a biological manner, with scientists being programmers and re-programmers of the digital information stored within DNA. Manufacturing is stated due to both 3D printing advances, while future nanotechnologists being programmers of advanced materials. Barnatt (2016) also emphasizes the advances in nanotechnology, genetic engineering, and biocomputers already signaling a new industrial convergence.

On the other hand, South Korea's megaproject of 5G (GIGAtopia) also presents future convergence of services more in detail, and more precisely in different sectors. Such as energy (smart energy), public safety (integrated safety), automotive and transportation (networked transportation and smart cars), next-generation media (3D holograms, etc.), and health care sectors (remote health care) (KT and Netmania, 2015).

Recent policy documents and projects of OECD show examples of industry convergence as well. One of these discussions is revolving around potential benefits stemming from the convergence of Nanotechnology, Biotechnology, Information Technology, and Cognitive Sciences (NBIC) (OECD, 2014a, 2014b). Another particular example is given from the semiconductor sector. Over the past three decades, there has been a shift in the structure of the sector such that different companies now often work in combination or sequentially to address different parts of the production process (for instance, design houses; mask houses; wafer companies; foundries; back-end processing; and electronic packaging). The process of technology convergence is leading also to organizational convergence in the manufacturing process, requiring an increasing amount of coordination between actors. Which also results in industry convergence. One other example, same as previously mentioned nanotechnology, synthetic biology is both a converging technology and industry (OECD, 2014a, 2014b). It is also mentioned that synthetic biology has applications

envisaged in important sectors such as energy, chemicals, medicine, environment, and agriculture. However, its definition and scope are still debatable, synthetic biology differs from genomics and it ranges from a natural extension of genetic modification and recombinant DNA technology to a new manufacturing paradigm.

Moreover, OECD STI Outlook 2016 and 2018 both represent forty KETs for the future and divide them into four categories as digital, biotechnologies, energy+environment (including autonomous vehicles, electric vehicles, drones), and advanced materials. Furthermore, one of the recently completed projects of OECD (2019) focusing on “Digital Innovation” (2019) and its case studies present the effect of digital transformation across sectors (retail, automotive, and agriculture) while also covering related KETs.

According to the aforementioned project, however, OECD does not focus on the transformation as co-evolutionary, as the focus is the digital transformation of the sectors. On the other hand, project findings and case studies in focus reflect and result in cross-sectoral convergence. For instance, Kern and Wolff (2019) particularly draw attention to the digital transformation of the automotive sector supply chain as one of the most important sectors for many developed countries, conducting semi-structured interviews with 27 experts from China and Germany in 2017 and 2018, employed in leading purchasing, production, and logistics functions at OEM, Tier 1, and Tier 2 suppliers. It is also emphasized that the automotive sector in the process of huge transformation by the effects of major technology-driven trends such as autonomous driving, electrification, car connectivity, and multimodality are predicted to lead to a huge transformation of the industry (Kaas et al., 2016). Accordingly, Kern and Wolff (2019) have investigated seven key technologies, which are IoT, automated guided vehicles, cloud computing, big data analytics, robotics, blockchain, mobile services, and technologies. They have observed that the source of the convergence of the industry is more established companies rather than SMEs. In this context, Rifkin (2014) emphasizes that industrial processes were improved for centuries, but the redesign of automotive, transportation, communication, and energy sectors simultaneously would lead to a new industrial revolution.

3.2. Cross-Sectoral Matching Analysis of Sectoral Dynamics Separately

As a second step of the descriptive study, cross-sectoral matching analysis of the secondary data is presented from the “R&D Based Solutions for Sectoral Problems Study”, which was undertaken by TÜBİTAK Department of Science, Technology and Innovation Policies (DoSTIP) (Saraçoğlu, 2014). Therefore, the scope of this part relies on the findings of the “R&D Based Solutions for Sectoral Problems Study” that covers fifteen industries in their contexts separately. Findings of cross-sectoral matching analysis are used as an input to the analysis method implemented for the case study in Chapter 5, as well as for the selection of the sectors, automotive and ICT.

The aforementioned study is an inventory-building study conducted by DoSTIP between the years 2013 and 2014, to determine the problems that can be solved via R&D in fifteen sectors. The inventory-building study aimed at the areas that needed more R&D activities, the technologies and products to be developed, and the activities that needed to be done to foster the national economy. The inventory-building study was held regarding fifteen sectors including nine national priority sectors under the National Science, Technology and Innovation Strategy 2011-2016 which was adopted at the 22nd meeting of Obsolete - Supreme Council for Science and Technology while taking into account other national policy documents such as Development Plans, Government Programs, or national strategies, such as Industrial Strategy, 2023 Export Strategy, Input Supply Strategy, Sectoral Reports, and Sector-Specific Strategies, etc. Fifteen sectors include automotive, machinery manufacturing, ICT, energy, food, water, health, aeronautics and space technologies, construction, chemistry, metal and mining industry, furniture, ceramics, textile, and transportation sectors.

The inventory-building study was held in three steps with the wide participation of private sector high-level representatives in targeted fifteen sectors. As a first step, a total of 1.553 sub-technology areas as R&D problems for each sector were determined via a web-based survey, and determined R&D problems were elaborated into Delphi statements. As a second step, consolidation, and prioritization studies were held via a web-based survey with the participation of 1.068 private sector firms/organizations.

Lastly, the third step included one-to-one interviews with sector experts (with wide participation of TOBB Sector Assemblies, private sector firms which have been supported by public R&D funding programs, R&D Centers, Technology Development Zone, etc.) to consolidate and final prioritization of determined statements. As a result, all determined R&D problems per each sector were consolidated and prioritized into either first eight to fifteen must subjects, including prioritized sub-technology areas. For instance, for the automotive sector 150 Delphi statements are determined in the participation of 123 private sector organizations, later those Delphi statements were consolidated into 61 statements and prioritized into 8 must subjects.

As a method of this part, first, prioritized Delphi statements of R&D problems, prioritized sub-technology areas, and related KETs from fifteen sectors are listed. Then cross-sectoral matching analysis is used and a “matching ratio” is defined as a metric. Basically, the matching ratio shows the ratio of matching of prioritized sub-technology areas and KETs across examined fifteen sectors. If the matching ratio is observed as more than 80%, compared sectors are considered as cross-sectorally converging. In other words, even in analyzing the needs of distinct sectors separately, the prioritization of the sub-technology areas and KETs showed cross-sectoral convergence.

Findings show that the ICT sector has the highest cross-sectorally matching ratio in all of the other sectors, which can not be considered as a surprise. On the other hand, it is most prominent that most cross-sectoral convergence can be seen between the ICT and automotive sectors, even while they are considered in their separated contexts (Figure 3.5). Figure 3.5 shows that almost all of the prioritized sub-technology areas (KETs) for the automotive sector are matching with the ones under the ICTs sector. Moreover, energy, machinery manufacturing, and aerospace sectors (which is already a converging industry from aeronautics and space) are very closely related to each other, as well as ICT and automotive sectors. Furthermore, advanced materials technologies are also very impactful for almost all fifteen sectors, however, it is not taken under consideration as a separated sector besides the metal and mining industry, and ceramics.

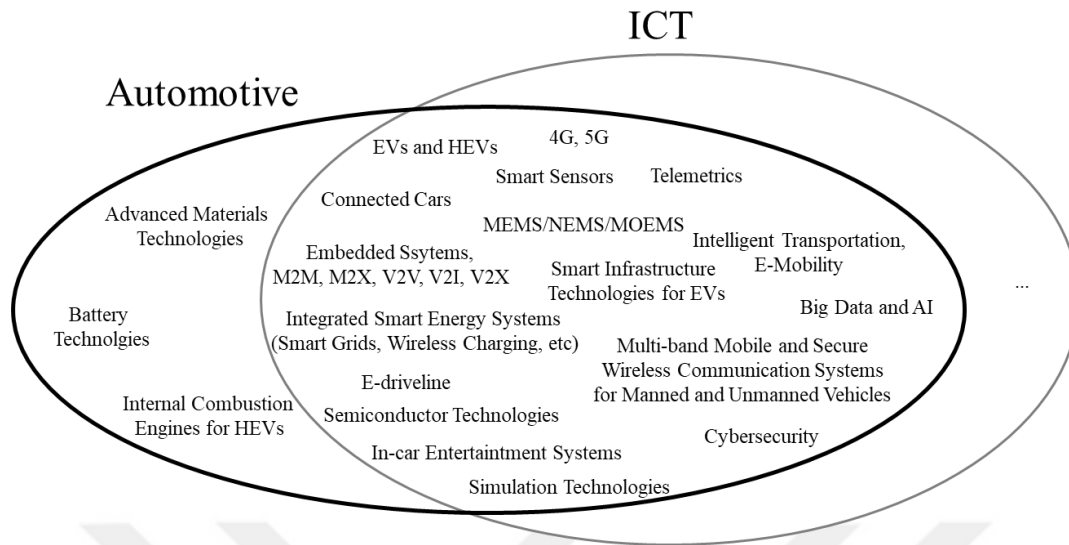


Figure 3.5. Result of the Cross-Sectoral Matching Analysis Taking Automotive and ICT Sectors Separately

3.3. Key Findings of the Descriptive Study of Cross-Sectoral Dynamics

This chapter brought a broader understanding of converging industries and contributed to the selection of automotive and ICT sectors for the case study, which is presented in Chapter 5. There is no doubt that with the digital transformation trend, more sectors, even traditional ones, transform rapidly. Recent studies present the impacts of the digital transformation on innovation across sectors, including automotive and ICT. Also, there are more converging industries besides horizontal and rather established sectors (and converging technologies) such as nanotechnology and biotechnology or more recently synthetic biology. These converging industries come front as functional foods (food industry + life sciences); packaging sector (pulp and paper industry + ICT); camera phones sector (telecom industry + camera technology); intelligent/smart buildings sector (construction technology + ICT). Moreover, it is determined that even in a separated sectoral analysis, automotive and ICT sectors demonstrate one of the highest levels of matching and converging regarding cross-sectoral perspective. Thus, in accordance with the research question, besides a better and wider understanding of converging industries, the descriptive study also provided input for the selection of automotive and ICT sectors for the case study.

CHAPTER 4

PROPOSING AN ANALYSIS METHOD FOR CROSS-SECTORAL DYNAMICS

This chapter presents the design of the proposed analysis method for the case study (presented in Chapter 5), as well as data and tools that are employed, regarding the main research question of this thesis that aims to measure the cross-sectoral co-evolutionary aspect of more than one dominant sector based on technology convergence. The analysis method is designed while taking into account the current mapping-measurement methods used in innovation systems (IS) literature and convergence literature in order to integrate the best method for the case study, which are also briefly presented in this chapter.

4.1. Steps for the Design of the Analysis Method

The design of the analysis method has four steps. Both quantitative and qualitative methods are regarded as necessary. Firstly, the findings of the theoretical background (Chapter 2) with a focus on SIS approach and demand-driven innovation policies, as well as convergence literature, are compiled in a contextual format. Secondly, after the formulation of the context of the analysis method for CSIS approach, using the context part, the focus is narrowed down on convergence in accordance with the main research question of this thesis. For this step, a brief review of current methods is also scrutinized in order to determine quantitative and qualitative analysis method dimensions and indicators, as well as data sources and tools. Thirdly, sectors for the case study are selected, especially regarding the results of the descriptive study (Chapter 3), and the scopes of selected sectors are reviewed. As the fourth and last step, the extraction method for keywords of the sectors for the case study is studied with regard to the scope of the selected sectors.

4.2. Context of the Analysis Method

As a result of the literature review, there are three main findings that current IS approaches draw attention to the need of CSIS approach while the trends of digital transformation and convergence are inevitably and rapidly increasing their impacts.

First main finding is that current IS approaches focus on the dynamics of only one dominant sector and co-evolution within its own dynamics. Secondly, they pay attention to the links and interdependencies of the dominant sector with related/supportive sectors. Therefore, current IS approaches do not directly analyze related/supportive sectors as one of the main components of the system. Last but not least, the main finding of the literature review is that there are no satisfactory methodologic studies, nor a holistic approach regarding technology convergence, cross-sectoral co-evolution, and industry convergence in the related literature, to examine the transformation of sectors, sectoral dynamics, and innovation systems, as well as the possible formation of new sectors with new dynamics as a result.

Moreover, from the demand-side innovation policies literature, it is observed that the relation between the technology-push and market-pull effects as in push-pull dynamics between science and technology convergences towards market convergence and the formation of industry convergence is also crucial while analyzing cross-sectoral dynamics. Especially an interactive, two-sided, and nonlinear push-pull dynamic is reviewed when convergence happens, causing the development of key enabling technologies (KETs), which are also observed to be one of the main triggers and drivers of cross-sectoral co-evolution.

Therefore, the context of the analysis method is mainly derived from the features of SIS approach (Malerba, 1999, 2004), Functional Dynamics (FD) Model (Bergek et al., 2005, 2008), and features of demand-side innovation policies focusing on the sequential process of industry convergence, which also shows the two-sided push-pull dynamic between convergence types. Building blocks of both approaches are taken under consideration as analysis units. Accordingly, in the design of the analysis

method for this thesis, because of aiming to capture the cross-sectoral perspective a **matching method of building blocks of an innovation system is determined as four dimensions and thirteen indicators**. These four dimensions and related indicators are given below:

- (1) Matching of Needs (such as legislations, strategies, domestic market formation, review of sectoral dynamics separately (such as a study like R&D based solutions for the private sector), etc.),
- (2) Matching of Capacity (such as R&D expenditure, scientific and technological capacity, etc.),
- (3) Matching of Strategical Importance (such as economic and social impacts, the case of the chosen sectors being KETs, etc.), and,
- (4) Matching of Global Trends Analysis (trend of world markets and strategies of main actors (countries, international S&T policy organizations, firms, etc.)).

Figure 4.1 presents in detail the abovementioned derivation process of the analysis method in two parts for CSIS approach. The first part on the top reflects the contextual format of the analysis method using theoretical background (Chapter 2), and the second part shows the dimensions and indicators derived from the context part.

It should be noted that the analysis method is designed as a complex model varying from the national level to global level criteria as the IS literature encompasses. However, since the research question of this thesis does not particularly focus on any national dynamics, but rather on SIS and cross-sectoral dynamics, global data sources are used for the case study. If the method and the research of this thesis had been considered to analyze a cross-sectoral dynamic for a country, or a country benchmarking, as well as more than two dominant sectors; then matching of “Needs”, “Capacity” and “Strategical Importance” dimensions would also be considered to analyze “national” side. Even then, the “Global Trend Analysis” dimension would not change, and it would cover global data, regarding cross-sectoral dynamics. Furthermore, it should be emphasized that a system consists of specific dynamics regarding actors and interrelations among the actors. Thus, analyzing individual actors

alone can not construct the whole picture of a system. Interactions among actors are rather crucial to understand the dynamics of the system since innovation does not happen to occur in isolation. As a result of the literature review, it is also obtained that innovation does not happen in one sector either. Convergence tends to form from specific interactions between system dynamics and has an impact on transforming those dynamics as well, thus creating a co-evolutionary process. Therefore, in order to understand innovation systems, it is needed to put together a complex and holistic model both pointing to actors and their interactions. For this reason, Figure 4.1 also shows the related links and similar structural components between each model that are used to derive the analysis method.

Some remarks can be given to understand Figure 4.1 better. Regarding the aim and the scope of this thesis, derived dimensions and indicators are separated as their direct or indirect use in the analysis method. Related links are shown in different colors, regarding the relation. For instance, in the context part, “Knowledge-Base” as a feature of SIS approach is related to the “Knowledge Development” and “Entrepreneurial Exploration” features under the FD Model, as well as “Science Convergence” and “Technology Convergence” features of demand-side innovation policies and the sequential process of industry convergence; which are all shown by red color. Accordingly, in the method part, they are considered as indicators under the “Matching of Capacity” dimension and color-coded as red.

Therefore, all color codes are used to show directly related links and structure components between each approach and in the method part. In addition, solid and dashed boxes are used to show the direct or indirect use of indicators in the analysis method regarding the scope of this thesis. **Color-coded solid boxes** show the indicators that are directly used/analyzed in the case study. **Color-coded dashed boxes** show the indicators that are relatively used/analyzed in the case study.

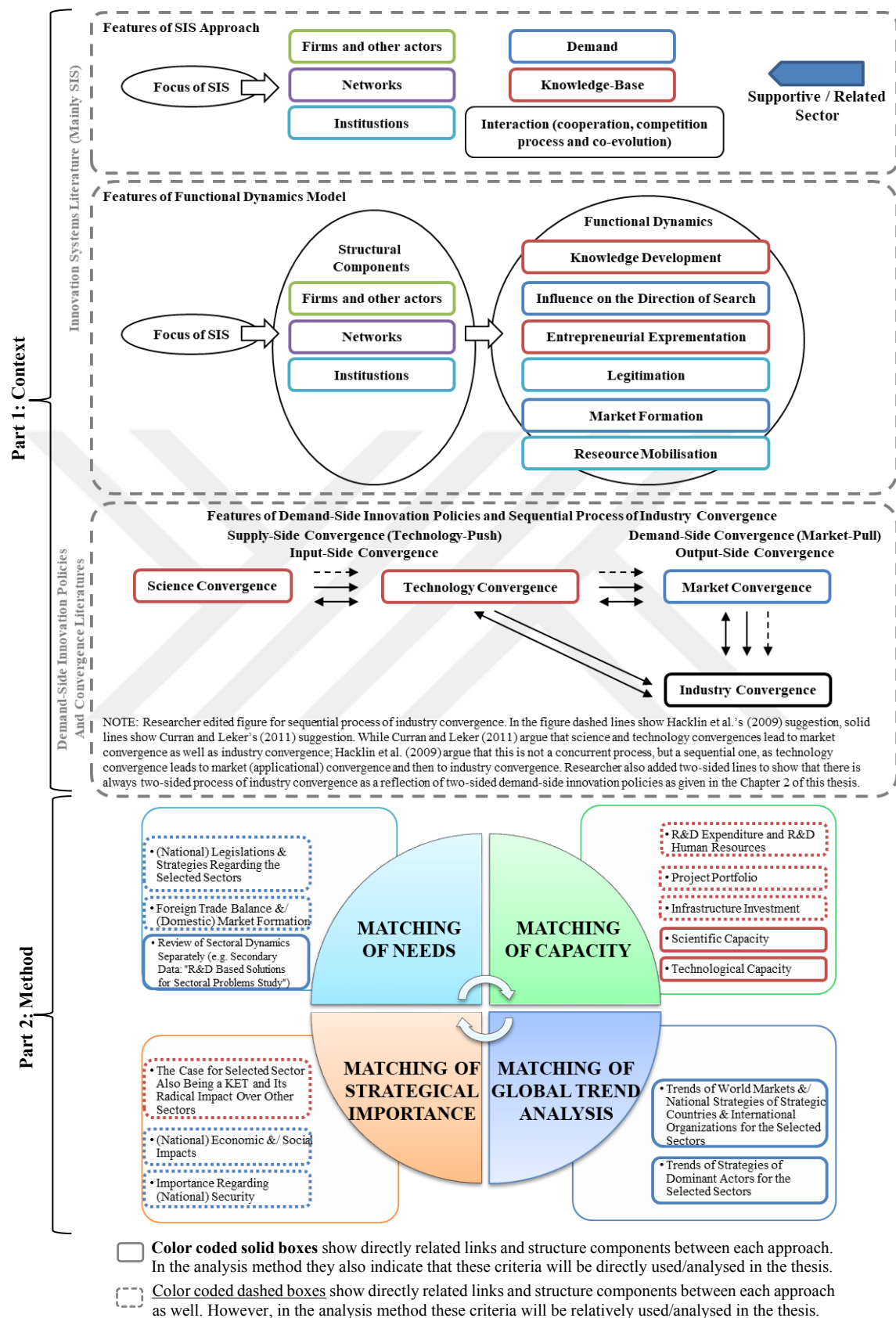


Figure 4.1. Design of the Analysis Method for CSIS Approach

4.3. Narrowing the Context and the Analysis Method for CSIS Approach

As aforementioned, for narrowing the context and analysis method for CSIS approach based on convergence, current methods for mapping IS and measuring convergence are also briefly reviewed.

For instance, Chang and Chen (2004) identify national, technological/sectoral, and regional approaches for IS, and argue methods for mapping IS as three following approaches; networking/snowball, community/membership, and clustering, which are shown in Table 4.1. According to Chang and Chen (2004), these three approaches for mapping IS are not mutually exclusive, and they all have weaknesses. For example, while the network approach excludes mapping informal interactions involved in both technological and market-bases, the community approach provides insights from informal links to frame institutional interaction in innovation systems. On the other hand, the cluster approach is stated as advantageous by using patents and publications for mapping interdependence among technology-bases in innovation systems. Nevertheless, it is also argued that using patents and publication analysis would not be a satisfying solution to identify all systemic links.

Table 4.1. Methods for Mapping Innovation Systems

Methods	Units of link	Advantages	Weaknesses
Networking/ Snowball Approach	Agent-base (firms/ organization)	Mapping inter-organizational formal activity	Not considering informal knowledge links
Community/ Membership Approach	Membership-based	Mapping governance structure	Not all firms have formal knowledge links with each community member
Clustering Approach	Patent/publication- based	• Mapping codified knowledge • Mapping technological interdependence	Not considering tacit knowledge mapping

Source: Chang and Chen, 2004, p. 30, Edited.

Furthermore, looking at the convergence literature it can be seen that common and repetitive analysis methods are being used. For instance, Jeong et al. (2015) discuss the measurement methods for all convergence types, which are shown in Table 4.2. As seen from the table, analysis sources and methods differ regarding the type of

convergence. For science convergence, it is reviewed that there are methodologic studies in the literature such as co-word analysis (Callon et al. 1986; Palmer, 1999), co-citation analysis (Small, 1977; Zitt et al., 2005; Leydesdorff, 2007; Porter and Rafols, 2009), co-authorship analysis (Porter et al., 2007), and journal subject category co-classification analysis (Noyons and Van Raan, 1998; Tijssen, 1992; Morillo et al., 2003; Schummer, 2004) based on scientific publications. These methods are stated as concrete even for interdisciplinary research.

For technology convergence, on the other hand, the co-citation or co-classification of technological categories of a patent (International Patent Classification-IPC) are mostly used (Curran et al., 2010; Curran and Leker, 2011; Jeong, 2014). Jeong et al. (2015) state that using patents as sources present data limitations, as well as boundaries than using scientific publications as a source. Actually, WIPO provides an official “IPC-Technology Concordance Table” that consists of five sectors and thirty-five fields showing the technology classification corresponding to IPC. However, it does not include sub-technology areas. Therefore, it is emphasized that these methods based on patents only show the nature of technology convergence at the macro level and remain experimental. While there are also studies that are using co-word analysis based on patents, they are not considered as providing generally adoptable data throughout technological domains (Curran and Leker, 2011; Jeong et al., 2015). Moreover, there are no applications in regard to technology convergence in the perspective of cross-sectoral dynamics.

Since market convergence and industry convergence are new research areas in respective of the abovementioned convergence types, measurement methods are considered as more developmental and immature (Curran et al. 2010; Curran and Lecker, 2011). To measure industry convergence, there are studies suggesting indicators by matching industrial classification (Standard Industrial Classification-SIC, NACE or ISIC) and IPCs (Fai and von Tunzelmann, 2001; Karvonen et al., 2012; Karvonen and Kässi, 2013), or by matching SIC and specific keywords for a patent (Curran et al. 2010). In the co-classification method, it is assumed that patents that are assigned to multiple IPCs present technology convergence. In addition, if a patent

shows heterogeneous sectors, it is presumed that it shows cross-sectoral convergence based on technology. Mostly the ratio of the aforementioned types of patents (namely convergent patents) in the total number of patents is used to rate the technology convergence. While the co-classification method allows for the identification of technological domains directly, those studies are considered as disregarding the stages of convergence. Accordingly, since the abovementioned analysis methods rely comprehensively on the applicable and adequate classification of technological boundaries, concordance tables have shortcomings. Therefore, at least, expertise in specific research areas, technology areas, and/or industrial contexts can be required to conduct the analysis method with appropriate keyword clusters and concordances. On the other hand, the measurement of market convergence is conducted via product specification analysis based on press releases. However, there is no common and measurable classification of parameters for products. Thus, the measurement of market convergence remains the most difficult and experimental one (Curran et al. 2010).

Table 4.2. Methodologies for Measuring Convergence

Convergence Type	Type of source	Method	Literature
Science	Scientific articles	Co-word analysis	Callon et al. (1986); Palmer (1999)
		Co-citation analysis	Small (1977); Zitt et al. (2005) Leydesdorff (2007); Porter and Rafols (2009)
		Co-authorship analysis	Porter et al. (2007)
		Journal subject category co-classification analysis	Noyons and Van Raan (1998); Tijssen (1992); Morillo et al. (2003); Schummer (2004)
Technology	Patents	IPC co-classification Analysis*	Curran and Leker (2011); Geum et al. (2012); Jeong (2014)
		Co-citation analysis	Geum et al. (2012)
Market	Press releases	Product specification analysis	Lee et al. (2009); Han et al. (2009)
Industry	General firm and industry information with patents	SIC-IPC concordance Analysis*	Athreye and Keeble (2000); Pennings and Puranam (2001); Fai and von Tunzelmann (2001); Curran et al. (2010); Karvonen et al. (2012)
		Input-output analysis	Xing et al. (2011)

* It is noted that, instead of SIC and IPC, case-specific but similar taxonomy is often used.
Source: Jeong et al., 2015, p.846.

From the perspective of the abovementioned methods, the nature of convergence at each level is considered distinct from the other. Therefore, specific methods are used by focusing on convergence type, while the consequences of the interaction between the convergence types are disregarded. In addition, while reviewing the multi-, cross-, and interdisciplinary research co-word and co-citation analyses are considered as accurate, but there are still limitations and shortcomings of the publication data using citations.

While these methods are considered as resulting in satisfactory attempts regarding the concept of convergence, there is no adequate method in integration with IS approaches, nor for examining cross-sectoral approaches including two or more distinct dominant sectors, including co-evolutionary dynamics of domains in focus. Therefore, the abovementioned methods are integrated into the design of the analysis method, but it is improved and differentiated for CSIS approach.

4.4. Determination of Dimensions and Indicators Quantitative and Qualitative Analysis Methods

After narrowing the context and analysis method in relation to the purpose of the main question of this thesis, the main dimensions of the analysis method are determined as technology convergence, cross-sectoral co-evolution, and industry convergence; as they are reviewed in Theoretical Background (Chapter 2) as well. On the other hand, since it is observed that industry convergence happens as a result of an interactive and iterative push-pull mechanism of all convergence types, and also all convergence types are in close interaction and influence with each other, science convergence and market convergence are considered as organic dimensions of the analysis method. Besides, because the formation and impact of “Key Enabling Technologies (KETs)” are observed as crucial as convergence process for cross-sectoral dynamics, and as a result of convergence and the two-sided push-pull dynamic, KETs are regarded as an organic dimension as well. However, it is also observed that for the determination of KETs all dimensions and indicators can be used.

Lastly, points such as the convergence between science and technology, or the dynamics of the convergence process are not disregarded as well. From this perspective, the aforementioned organic dimensions are integrated into the analysis method as the main and measurable dimensions; and science, technology, and market convergences are analyzed separately by their respective and related methods and data. Accordingly, six indicators are determined and since it is aimed to analyze the cross-sectoral perspective, the matching method is applied for all of them based on keywords, namely **“Cross-Sectoral Matching Analysis Method”**.

Figure 4.2 shows the narrowing process in connection with Figure 4.1, Part 2, as well as the proposed analysis method regarding CSIS approach focusing on convergence and cross-sectoral co-evolutionary dynamics as the aftermath of the narrowing process. Table 4.3 summarizes the dimensions and indicators; shows the details for method, data, and tools used in the analysis method based on Figure 4.2, and the aftermath of integrating the organic dimensions to the analysis method, while also showing the concordances with Figure 4.1, Part 2.

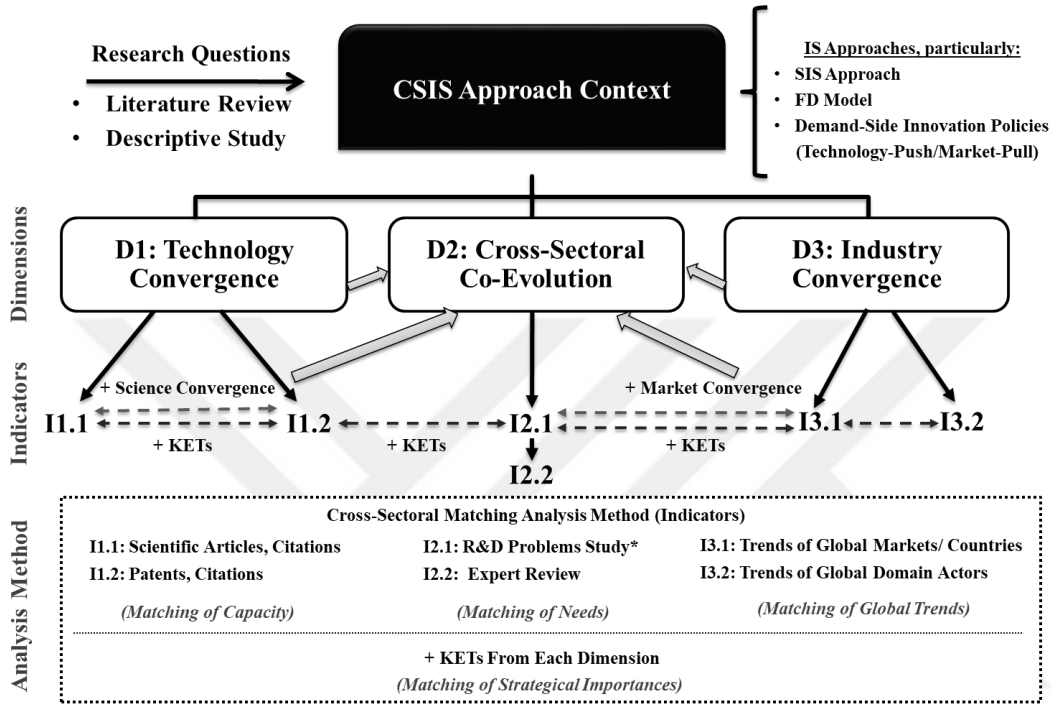
In this regard, after integrating organic dimensions, the analysis method is formed as the following (Table 4.3, D: Dimension, I: Indicator);

- (1) Under **D1 “Technology Convergence”**; **“Science Convergence”** is regarded as **D1.1** and **“Technology Convergence”** is as **D1.2**. Which are in concordance with “Scientific Capacity” and “Technological Capacity” respectively, regarding the **“Matching of Capacity”**. Indicators for D1.1 are determined as scientific articles, citations, co-citations (I1.1), and for D1.2 as patents, citations, and co-citations of patents (I1.2). Quantitative analysis methods are used for both.
- (2) **D2 is “Cross-Sectoral Co-Evolution”** and this dimension as a whole is considered in concordance with **“Matching of Needs”**. Expert judgments are considered valuable to analyze cross-sectoral co-evolution and to determine KETs. Therefore, qualitative analysis methods are regarded as better suited for this dimension, especially regarding reviewing the needs and dynamics of

sectors separately. Besides, for taking sectoral perspectives and improve and/or strengthen quantitative analysis, a qualitative analysis is regarded as necessary. Moreover, it is considered that to observe cross-sectoral dynamics, especially co-evolution, taking sectors separately and excluded from the convergence effect is crucial. As would be remembered a study that corresponds to this need has already been presented as one of the parts of the Descriptive Study (Section 3.2). A cross-sectoral matching analysis of sectoral dynamics based on “R&D Based Solutions for Sectoral Problems Study” has been conducted. However, this study is considered as one of the indicators (I2.1), since it is already used in Chapter 3, this indicator is not used again for the case study while the results are not disregarded. For this matter, “Expert Review” is determined as the second indicator (I2.2), and a structured survey (an online expert contribution form) is prepared using the cross-sectoral matching analysis method including prioritization of sub-technology areas, a Delphi questionnaire, and prioritization of convergence type in the cross-sectoral perspective. It should be noted that I2.1 should be applied for further case studies where this type of study is not held before and it can be applied using “Expert Review” (I2.2) so that these two indicators can be used for both purposes as combined into one indicator.

- (3) **D3 is “Industry Convergence”**. As it is explained before, industry convergence is regarded as a result of the cross-sectoral dynamics and other convergence types. Therefore, **after the integration of organic dimensions, “Market Convergence” is regarded as D3**. For this matter, quantitative analysis methods based on secondary data are regarded as better suited for this dimension, especially market trend analysis. Therefore. “Trends of Global Markets / Countries” (I3.1) and “Trends of Global Domain Actors” (I3.2) are determined as two indicators of this dimension. As can be seen, this dimension as a whole is considered in concordance with **“Matching of Global Trends”**.
- (4) Even though **KETs** is one of the organic dimensions, it is not regarded as a separate dimension per se, because KETs can be determined from all of the abovementioned dimensions. KETs are both drivers and the result of cross-sectoral dynamics, especially when convergence happens. Therefore, separate

indicators are not determined and all of the abovementioned indicators are used to determine KETs. Lastly, KETs are considered as in concordance with “**Matching of Strategic Importance**”.



Note: While three dimensions are regarded as the main dimensions of this thesis, as they are reviewed in Theoretical Background (Chapter 2), the signal (+) shows the organic dimensions as the aftermath of the narrowing process. Therefore, they are included in the analysis method. In addition, shown with (*), R&D Problems Study used in descriptive study, Chapter 3.

Figure 4.2. Proposed Analysis Method for the Case Study Regarding CSIS Approach

In the application of the proposed analysis method, some limitations might be expected and should not be disregarded while iterative solutions should be developed. One of the limitations can be related to the sources and the requirements of the data sources and databases. On the other hand, it can be expected that selected sectors and the determined scope of the selected sectors (via, sub-technology areas and keyword clusters) would be affecting the analysis results and cause path-dependency. Therefore, it is essential that cross-sectoral matching analysis is eliminated from path-dependency limitations while reflecting the dynamics of all selected dominant sectors with sector-specific features. It is also suggested to always support quantitative analysis methods with qualitative analysis methods.

Table 4.3. Summary of Dimensions and Indicators of the Cross-Sectoral Matching Analysis Method

Dimensions (D) (From Literature Review and Descriptive Study)	Dimensions After Integrating Organic Dimensions from the Context and Method (D) (Concordance with Figure 4.1, Part 2)	Indicators (I) (Concordance with Figure 4.1, Part 2)	Analysis Method (Cross-Sectoral Matching Analysis with Quantitative/Qualitative Analysis Methods)
D1: Technology Convergence ±: <u>Science Convergence</u>	Matching of Capacity (Scientific Capacity): <u>D1.1: Science Convergence</u>	Matching of Capacity (Scientific Capacity): <u>I1.1: Scientific Articles, Citations, Co-Citations</u>	Quantitative Analysis: Bibliometric analysis using scientific publications/citations data (keyword matching using TAs/keyword clusters)
	Matching of Capacity (Technological Capacity): <u>D1.2: Technology Convergence</u>	Matching of Capacity (Technological Capacity): <u>I1.2: Patents, Citations, Co-Citations</u>	Quantitative Analysis: Bibliometric analysis using patent/patent citations data (keyword matching using TAs/keyword clusters)
D2: Cross-Sectoral Co-Evolution	<u>D2:</u> <u>Cross-Sectoral Co-Evolution</u>	Matching of Needs: I2.1: R&D Problems Study	Qualitative Analysis: Inventory-building study with semi-structured interviews
		Matching of Needs: <u>I2.2: Expert Review for Cross- Sectoral Co-Evolution</u>	Qualitative Analysis: Matching analysis of TAs by sector experts. • Prioritization of sub-technology areas • Delphi questionnaire • Prioritization of convergence types
D3: Industry Convergence ±: <u>Market Convergence</u>	<u>D3: Market Convergence</u>	Matching of Global Trends: <u>I3.1: Trends of Global Markets / Countries</u>	Quantitative Analysis: Global trend analysis using strategies of main actors in selected sectors (trend matching based on keywords, using TAs).
		Matching of Global Trends: <u>I3.2: Trends of Global Domain Actors</u>	Quantitative Analysis: Global trend analysis using strategies of main actors in selected sectors (trend matching based on keywords, using TAs).
±: KETs for each dimension	Matching of Strategical Importances: ±: KETs for each dimension	Matching of Strategical Importances: All indicators.	

Note 1: Dimensions and indicators that are **bolded and italic** indicate that they are directly used in the analysis method for the case study (Chapter 5). However, I2.1 is used as a part of descriptive study (Chapter 3), therefore it is not used in the analysis method again, while its sources and results are not disregarded.

Note 2: KETs is not a separate dimension and they are determined by all indicators.

Note 3: Colors indicate the concordance with Figure 4.1, Part 2.

4.5. Selection of Sectors for the Case Study for CSIS Approach

For the selection of sectors, findings from the descriptive study (Chapter 3) are considered primarily and foremost, which is composed of two parts. In the descriptive study first, sectors in the context of convergence are examined, and findings of descriptive research are presented. Second, to observe the converging sectors independent from the boundaries and externalities that cause convergence, a cross-sectoral matching analysis is made using secondary data of “R&D Problems Study” which considers fifteen sectors separately.

From the results of the descriptive study both in the context of converging industries and excluded from convergence effects, automotive and ICTs demonstrated significant and suitable aspects for the cross-sectoral matching analysis method, in accordance with the aim of this thesis. First of all, they are both dominant sectors. Besides, both of them being composed of dominant actors in the global RDI chain is also taken into consideration. Also, both sectors that are most influenced and influential by new economy trends such as technology convergence, digital transformation, and converging technologies (such as AI, IoT, embedded systems, broadband technologies, robotics, etc.), quantification, virtualization, molecular integration, integration/interaction between networks, personalization and globalization.

Both sectors can also be considered as converging industries separately. It is mostly observed that automotive is highly affected by the ICTs; however, it is also an interesting perspective if the effects are co-evolutionary across sectors. Therefore, it is expected that the case study regarding automotive and ICTs will also bring a cross-sectoral co-evolutionary perspective.

4.5.1. Scope of the Selected Sectors

For the scope of the Automotive and ICTs sectors, OECD technology classification (Galindo-Rueda and Verger, 2016), European Classification of Economic Activities (NACE) Rev. 2 sectoral classification, and EUROSTAT High-Tech Classification of Manufacturing Industries based on NACE Rev.2 are considered (EUROSTAT, 2007a, 2007b), as well as expertise referencing studies to understand the contexts of sectors (Pavleniek, 2017). For the Automotive sector, including manufacturing and services, mainly NACE 29 is used. For ICTs sector, including manufacturing and services, mainly NACE 26 is used.

Table 4.4. Scope of Automotive Sector, NACE Rev.2

Automotive Sector, Manufacturing and Services, Mainly NACE 29

C - Manufacturing

C.28 - Manufacture of machinery and equipment n.e.c.

- C.28.1 - Manufacture of general-purpose machinery
- C.28.11 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
- C.28.15 - Manufacture of bearings, gears, gearing and driving elements

C.29 - Manufacture of motor vehicles, trailers and semi-trailers

- C.29.1 - Manufacture of motor vehicles
- C.29.10 - Manufacture of motor vehicles
- C.29.2 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
- C.29.20 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
- C.29.3 - Manufacture of parts and accessories for motor vehicles
- C.29.31 - Manufacture of electrical and electronic equipment for motor vehicles
- C.29.32 - Manufacture of other parts and accessories for motor vehicles

G - Wholesale and retail trade; repair of motor vehicles and motorcycles

- G.45 - Wholesale and retail trade and repair of motor vehicles and motorcycles
- G.45.1 - Sale of motor vehicles
- G.45.11 - Sale of cars and light motor vehicles
- G.45.19 - Sale of other motor vehicles
- G.45.2 - Maintenance and repair of motor vehicles
- G.45.20 - Maintenance and repair of motor vehicles
- G.45.3 - Sale of motor vehicle parts and accessories
- G.45.31 - Wholesale trade of motor vehicle parts and accessories
- G.45.32 - Retail trade of motor vehicle parts and accessories
- G.45.4 - Sale, maintenance and repair of motorcycles and related parts and accessories
- G.45.40 - Sale, maintenance and repair of motorcycles and related parts and accessories

Source: EUROSTAT, 2007a, 2007b; Pavleniek, 2017, p.210.

Table 4.5. Scope of ICTs Sector, NACE Rev.2

ICTs Sector, Manufacturing and Services, Mainly NACE 26	
C – Manufacturing	
C.26 - Manufacture of computer, electronic and optical products	
C.26.1 - Manufacture of electronic components and boards	C.26.51 - Manufacture of instruments and appliances for measuring, testing and navigation
C.26.11 - Manufacture of electronic components	C.26.52 - Manufacture of watches and clocks
C.26.12 - Manufacture of loaded electronic boards	C.26.6 - Manufacture of irradiation, electromedical and electrotherapeutic equipment
C.26.2 - Manufacture of computers and peripheral equipment	C.26.60 - Manufacture of irradiation, electromedical and electrotherapeutic equipment
C.26.20 - Manufacture of computers and peripheral equipment	C.26.7 - Manufacture of optical instruments and photographic equipment
C.26.3 - Manufacture of communication equipment	C.26.70 - Manufacture of optical instruments and photographic equipment
C.26.30 - Manufacture of communication equipment	C.26.8 - Manufacture of magnetic and optical media
C.26.4 - Manufacture of consumer electronics	C.26.80 - Manufacture of magnetic and optical media
C.26.40 - Manufacture of consumer electronics	
C.26.5 - Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks	
G - Wholesale and retail trade; repair of motor vehicles and motorcycles	
G.46 - Wholesale trade, except of motor vehicles and motorcycles	
G.46.5 - Wholesale of information and communication equipment	
G.46.51 - Wholesale of computers, computer peripheral equipment and software	
G.46.52 - Wholesale of electronic and telecommunications equipment and parts	
J - Information and communication	
J.58 - Publishing activities	J.62.0 - Computer programming, consultancy and related activities
J.58.2 - Software publishing	J.62.01 - Computer programming activities
J.58.21 - Publishing of computer games	J.62.02 - Computer consultancy activities
J.58.29 - Other software publishing	J.62.03 - Computer facilities management activities
J.61 - Telecommunications	J.62.09 - Other information technology and computer service activities
J.61.1 - Wired telecommunications activities	J.63 - Information service activities
J.61.10 - Wired telecommunications activities	J.63.1 - Data processing, hosting and related activities; web portals
J.61.2 - Wireless telecommunications activities	J.63.11 - Data processing, hosting and related activities
J.61.20 - Wireless telecommunications activities	J.63.12 - Web portals
J.61.3 - Satellite telecommunications activities	J.63.9 - Other information service activities
J.61.30 - Satellite telecommunications activities	J.63.91 - News agency activities
J.61.9 - Other telecommunications activities	J.63.99 - Other information service activities n.e.c
J.61.90 - Other telecommunications activities	
J.62 - Computer programming, consultancy and related activities	
S - Other services activities	
S.95 - Repair of computers and personal and household goods	
S.95.1 - Repair of computers and communication equipment	
S.95.11 - Repair of computers and peripheral equipment	
S.95.12 - Repair of communication equipment	

Source: EUROSTAT, 2007a, 2007b.

4.6. Determination of TAs and Keywords for the Case Study

Keywords are used to effectively express the core and limits of the scientific research area, and technology context (Hood and Wilson, 2001), and there are several keyword extraction methods. One of the methods builds on Latent Semantic Analysis (LSA), which is used by Ziegler (2009) in order to cluster terms into manageable “concepts”. LSA is based on a well-known and commonly used technique in linear algebra called “Principal Component Analysis”. Often, very closely related keywords can be produced such that they could be regarded as synonyms. LSA produces a set of “concepts”, each of which is a weighted combination of every term in the research area, based on the co-occurrence of terms in documents. LSA also aids in term cleaning, where terms that do not have a strong weighting within any of the concepts generated by LSA are discarded (Camiña, 2010). Another method is using a bibliographic analysis and text mining. In this method, a text-mining analysis can be used which can map the keywords in related sector/technology area with a technical perspective, and keyword co-occurrence analysis can be used in terms of occurrence patterns and interrelations (van Eck and Waltman 2014).

While considering sectoral (NACE), patent (IPC), and bibliometric classifications (All Science Journal Classification, SCOPUS Database), expert judgments and reviews from the existing works (such as technology prioritization, technology roadmapping, etc.) are also considered (mainly technical reviews of technology areas/sector experts and/or advisory board members in TÜBİTAK) to finalize the sub-technology areas of sectors, and keyword clusters (Saraçoğlu, 2014).

Mainly, four steps of the keyword extraction method for the selected sectors using sub-technology areas and co-occurrence analysis are applied to see patterns and interrelations in a cross-sectoral matching analysis. First of all, the sub-technology area is searched in SCOPUS Database in its widest form, by choosing the main research area of technology (for example, engineering, computer science, etc.). Secondly, out-of-scope and very general ones are eliminated from the most used keywords in these publications. Later, a new search is made with the new set of keywords, while the main

area is selected and the results are limited. The most used keywords are extracted. By doing a few iterations in this way, lastly, a great deal of consistency is achieved in the keyword clusters with the set in the previous iteration. The results were checked again with the expert judgments. Moreover, cross-checked via using IEEE Xplore Database⁵. As a result, six sub-technology areas covering automotive sector and fourteen sub-technology areas covering ICT sector are determined with their keyword clusters respectively (Table 4.6).

Table 4.6. Sub-Technology Areas for Automotive and ICT Sectors

Six Sub-Technology Areas of Automotive Sector (AUTO_TA1-6)	AUTO_TA1: AUTO Battery Technologies
	AUTO_TA2: Electric&Hybrid Vehicle Technologies
	AUTO_TA3: AUTO Material Technologies
	AUTO_TA4: Engine and Engine Transmission Components (Powertrain)
	AUTO_TA5: AUTO Embedded Systems
	AUTO_TA6: AUTO Innovative Design
Fourteen Sub-Technology Areas of ICT Sector (ICT_TA1-14)	ICT_TA1: Information Security (including Cybersecurity&Cryptography)
	ICT_TA2: Cloud Computing (including Virtualization&Super Computing)
	ICT_TA3: Digital Technologies
	ICT_TA4: Display Technologies
	ICT_TA5: Photonics
	ICT_TA6: Broadband Technologies (including Wired/Wireless Communication, IP Technologies & Telecom Equipment)
	ICT_TA7: Embedded Systems
	ICT_TA8: Power Electronics
	ICT_TA9: MEMS, NEMS, MOEMS
	ICT_TA10: Semiconductors
	ICT_TA11: Mobile Communication Technologies (including IoT&M2M)
	ICT_TA12: Robotics&Mechatronics (including AI&ML)
	ICT_TA13: Software Technologies
	ICT_TA14: Data Technologies

⁵ IEEE Xplore Database provides a high quality technical literature for engineering and technology, retrieved from: <https://ieeexplore.ieee.org/Xplore/home.jsp>.

CHAPTER 5

CASE STUDY: CROSS-SECTORAL INNOVATION SYSTEM ANALYSIS FOR AUTOMOTIVE & ICT SECTORS

This thesis aims to investigate the co-evolutionary aspect of more than one dominant sector based on technology convergence regarding the perspective of innovation system approaches. For this matter, a **cross-sectoral matching analysis method** is designed that includes both quantitative and qualitative methodological aspects while considering current mapping-measurement methods used in innovation systems (IS) literature and convergence literature, respectively (explained in Chapter 4). The analysis method designed in Chapter 4 is conducted as a case study and applied for automotive and ICT sectors in this chapter.

Also, in relation to the main research question given above, one of the two auxiliary research questions concerning the formation of “Key Enabling Technologies (KETs)” based on the conceptualization of the cross-sectoral co-evolution, is also aimed to be examined via the case study as given in the analysis method (Chapter 4). The main elements (dimensions and indicators, methods, data sources, and tools) of the analysis method for the case study can be seen in Figure 4.2 and Table 4.3 (Chapter 4), respectively. The reason for selecting automotive (AUTO) and ICT sectors and the scope of the sectors are also elaborated in Chapter 4 (Section 4.5 and Section 4.5.1). One of the main reasons for choosing the AUTO and ICT sectors is that both of these sectors are dominant sectors, and have very specific dynamics. Thus, AUTO and ICT sectors are considered adequate for cross-sectoral analysis, especially regarding SIS, converging and co-evolution perspectives.

The organization of the case study is composed of mainly two sections, **quantitative analysis**, and **qualitative analysis**.

Firstly, **quantitative analysis** section is presented for **science convergence**, **technology convergence**, and **market convergence** in AUTO and ICT sectors. For all convergence types, sub-technology areas, and keywords; cross-sectoral matching method, and related mapping, visualization, text-mining tools are applied; which are given in detail under the related section; also explained in the design of the analysis method in Chapter 4. Secondly, **qualitative analysis** section is conducted and presented where expert judgments are examined via structured expert contribution form. Similar to quantitative analysis, **all three convergence types** are covered and examined. Cross-sectoral matching analysis method based on sub-technology areas and keywords is also applied. All analyses are presented with the two sub-sections as the scope and the method of the analysis (including related assumptions and/or limitations, applied specific methodologies, used data sources and tools), and analysis results and evaluation parts.

It should also be noted that, as the reason for this thesis being written in Turkey, available data on Turkey is also covered and examined briefly, and can be seen in Appendix E, including comparisons with related part of the analyses parts.

5.1. Quantitative Analysis

From now on, quantitative analyses of science, technology, and market convergences are presented in consecutive sub-sections.

5.1.1. Quantitative Analysis for Science Convergence

First, scope and method sub-section, then analysis results and evaluation sub-section for quantitative analysis for science convergence are given below.

5.1.1.1. Scope and Method

Basic methodologies for measuring science convergence are co-word analysis, co-citation analysis, co-authorship analysis, and “journal subject category” co-

classification analysis based on scientific articles as sources (Table 4.2, Jeong et al., 2015, p.846). For this matter, bibliometric analysis using scientific publications data in selected sectors is used. Cross-sectoral matching analysis method is applied using sub-technology areas composed of keywords via co-word analysis using retrieved data from the SCOPUS Database. Then, co-occurrence mapping is prepared using author keywords using VOSviewer.

For **AUTO sector** there are six sub-technology areas; that are determined by (AUTO_TA1-6) and six sub-technology area keyword clusters that are determined by [AUTO_TA1-6_AKC], meaning all six sub-technology areas are composed of keyword clusters separately that form them, and as a whole, they compose the AUTO sector [AUTO_AKC]. Six sub-technology areas for AUTO sector are as the following;

- (AUTO_TA1) AUTO Battery Technologies,
- (AUTO_TA2) Electric and Hybrid Vehicle (EHV) Technologies,
- (AUTO_TA3) AUTO Material Technologies,
- (AUTO_TA4) Engine and Engine Transmission Components (Powertrain),
- (AUTO_TA5) AUTO Embedded Systems,
- (AUTO_TA6) AUTO Innovative Design.

Similarly, for the **ICT sector** there are fourteen sub-technology areas; that are determined by (ICT_TA1-14) and fourteen sub-technology area keyword clusters that are determined by [ICT_TA1-14_AKC]. All fourteen sub-technology areas are composed of keyword clusters separately that form them and as a whole, they compose the ICT sector [ICT_AKC]. Sub-technology areas for the ICT sector are as the following;

- (ICT_TA1) Information Security (including Cybersecurity and Cryptology),
- (ICT_TA2) Cloud Computing (including Virtualization and Super Computing),
- (ICT_TA3) Digital Technologies,
- (ICT_TA4) Display Technologies,

- (ICT_TA5) Photonics,
- (ICT_TA6) Broadband Technologies (including Wired/Wireless Communication, IP Technologies, and Telecom Equipment),
- (ICT_TA7) Embedded Systems,
- (ICT_TA8) Power Electronics,
- (ICT_TA9) MEMS, NEMS, MOEMS,
- (ICT_TA10) Semiconductors,
- (ICT_TA11) Mobile Communication Technologies (including IoT and M2M),
- (ICT_TA12) Robotics and Mechatronics (Including AI and ML),
- (ICT_TA13) Software Technologies,
- (ICT_TA14) Data Technologies.

For the cross-sectoral matching analysis method firstly, conjunction of sector clusters as AUTO-ICT sector and its coding is prepared. However, it did not work because of the coding requirements/limitations of the SCOPUS Database. To solve the problem, the aforementioned keyword clusters are used to analyze ICT-based AUTO sector and AUTO-based ICT sector, separately. For example, after the limitations are concerned, for analyzing ICT-based AUTO sector, keyword clusters that form each of fourteen sub-technology areas of the ICT sector are separately used merged with the AUTO sector as a whole ([AUTO_AKC] + [ICT_TA1-14_AKC]). Similarly, for AUTO-based ICT sector, keyword clusters that form each of six sub-technology areas of the AUTO sector are separately used merged with the ICT sector ([ICT_AKC] + [AUTO_TA1-6_AKC]). Figure 5.1 below shows the logic of sub-technology areas and keyword clusters that are used in cross-sectoral matching analysis method based on keywords.

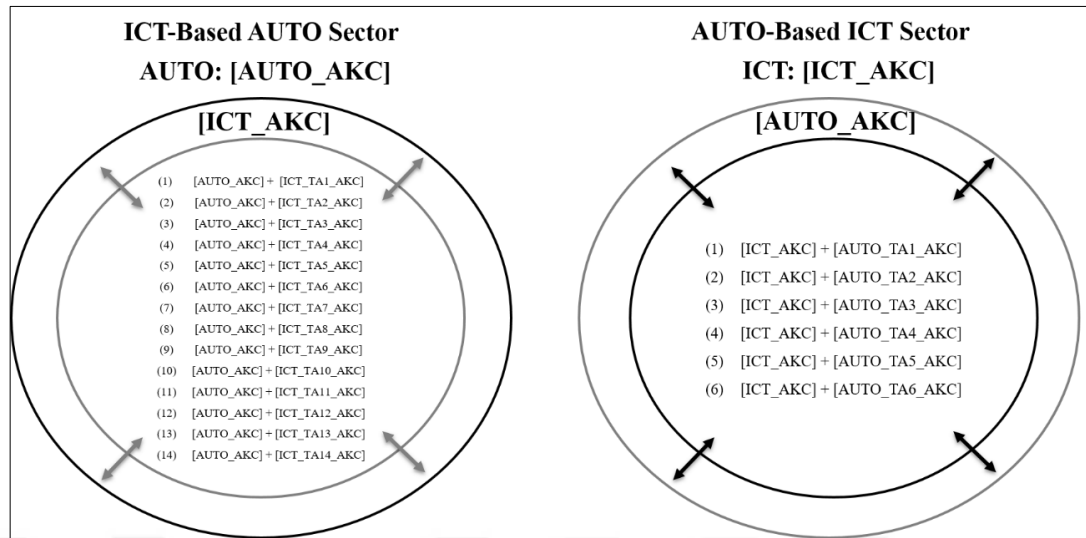


Figure 5.1. The Logic of Cross-Sectoral Matching Analysis Method for Science Convergence Based On Matching TAs & Keyword Clusters of Automotive & ICT

There are a few limitations and assumptions for the analysis. First of all, scientific data are retrieved from SCOPUS Database; therefore, retrieval limitations of the aforementioned database are considered while analyzing the data. Moreover, all data are pre-analyzed in comparison by the tools provided in SCOPUS Database and SciVal, to be able to make the best retrieval decision. As can be expected, the coding is very long, thus created coding and retrieval technical challenges, which are solved iteratively. AUTO-based ICT sector coding consists of almost 20 thousand words with 38 pages. ICT-based AUTO sector coding consists of almost 34 thousand words with 118 pages. Therefore, the analysis on its own required solving technical challenges that databases can not offer. Table B.1 (Appendix B) shows the coding example for cross-sectoral keyword matching analysis method for AUTO + ICT_TA1_AKC (which is Information Security sub-technology area for the ICT sector) for a better understanding.

As another limitation, SCOPUS Database does not allow to retrieve all information more than the first 2000 counts, it only allows citation information to be retrieved if the counts are more than 2000. Sequencing the data while retrieving and merging after retrieval as one data document is one of the solutions. However, technical issues forced a decision to be made between using the data that can be retrieved fast or waiting for

the technical issues to be solved. Moreover, as aforementioned, all data pre-analyzed and compared yearly for the best decision before the data retrieval. For the analysis, the first 2000 counts for some sub-technology areas were considered sufficient according to the results of the pre-analysis that the sub-technology areas with more than the first 2000 data -and less- were comparable to each other on a yearly basis. In addition, it is justified by the pre-analysis that the analysis results would have not changed in the case of retrieving the whole data. Therefore, for some of the sub-technology areas and keyword clusters, which were consisted of more than 2000 counts, the decision was made to retrieve and analyze only the first 2000 counts. Sub-technology areas and keyword clusters that are composed of only the first 2000 counts are as follows. For ICT-based AUTO sector data; AUTO + Power Electronics, AUTO + Semiconductors, AUTO + Robotics and Mechatronics, and AUTO + Data Technologies. For AUTO-based ICT sector data; ICT + EHV Technologies, ICT + Engine and Engine Transmission Components (Powertrain), ICT + AUTO Embedded Systems. It should also be noted that, while analyzing, duplications are eliminated for all of the data. Moreover, text clustering and text mining methods are conducted via VOSviewer, and partly via Semantria.

Another limitation is the timeline preference. For every sub-technology area, data between the years 2004-2018 are retrieved for a wider perspective of the analysis. Nevertheless, ten years of a standard timeline is chosen while analyzing the data. By using these sector clusters consisting of sub-technology areas and keywords, a co-word analysis is done via matching keyword clusters for each sub-technology area under both sectors retrieving values between the years 2007-2017 timeline. The reasoning for choosing this timeline has two justification points. One of the reasons is that ten years of a timeline is assumed adequate to observe convergence dynamics. In fact, because of “The DARPA Grand Challenge: Autonomous Robotic Ground Vehicles”, the year 2004 comes forward as an important milestone in the convergence of AUTO-ICT sectors. Given 2-3 years for the development of the technology after the DARPA Challenge and convergence effect on sectors, the timeline between the years 2007-2017 is regarded as a solid timeline to observe cross-sectoral convergence.

Analysis parts can be summarized as follows. Firstly, to observe the sub-technology areas that are becoming more frequent in the cross-sectoral perspective, publication counts between the years 2007-2017 are examined. This way, the focal sub-technology areas respectively for ICT-based AUTO sector and AUTO-based ICT sector are shown. Secondly and similarly, sub-technology areas that are becoming more frequent between the years 2007-2017 based on citation counts are given.

Thirdly, to observe co-evolutionary cross-sectoral perspective co-occurrence mappings are prepared, by showing main clusters, networks, total link strengths based on citations, and year-based convergence respectively for ICT-based AUTO sector and AUTO-based ICT sector. Co-occurrence for author keywords and full counting methods are applied in the following three examinations;

- (1) Network Visualization is applied with weights chosen as occurrences. With this analysis, cross-sectoral clustering with related ties is aimed to examine.
- (2) Overlay Visualization is applied with weights chosen as occurrences and scores chosen as average publication year. With this analysis, the timeline of cross-sectoral convergence and co-evolutionary aspects are aimed to examine.
- (3) Overlay Visualization is applied with weights chosen as total link strengths and scores chosen as average citations. Similar to the bullet (2), internal dynamics with their ties and emergent sub-technology areas are aimed to examine by their citation values.

It should be noted that only edited versions of the mappings are presented, which means that text mining is applied and all keywords are standardized to get more sound results. For example, plural “electric vehicles”, and abbreviated keywords, “EV” or “EVs”, converted into a single standard keyword as “electric vehicle”, if applicable. Synonyms with different spellings are converted into a single keyword such as “lithium-ion battery”, “li-ion battery”, etc. to “li-on battery”. General keywords, such as automotive, are eliminated.

Fourthly, countries are examined to determine the prominent five countries with the most publications per each sub-technology in the cross-sectoral perspective. Lastly, affiliations are examined to show the science convergence via institutions. The results of these both examinations are expected to show the dominant actors in the cross-sectoral perspective, as well as co-evolutionary aspects of these actors for ICT-based AUTO sector and AUTO-based ICT sector, respectively.

5.1.1.2. Analysis Results and Evaluation

For ICT-based AUTO sector, sub-technology areas becoming more frequent between the years 2007-2017 in the automotive sector based on the ICT sector keyword bibliometric analysis are given below in Figure 5.2. According to the figure, the most frequent five sub-technology areas are as following; Power Electronics, Semiconductors, Data Technologies, Robotics and Mechatronics, and Embedded Systems. This observation suggests that AUTO sector is becoming more and more ICT dependent. Especially when looking at the annual distribution of the sub-technology areas mentioned above based on publications; it is seen that the share of Power Electronics, Semiconductors, and Data Technologies are increasing at an increasing rate on an annual basis, while others are showing a constant yet increasing trend.

On the other hand, Figure 5.3 shows sub-technology areas cited frequently between 2007-2017 in the ICT-based automotive sector keyword bibliometric analysis. Similar to Figure 5.2, the top five frequent sub-technology areas based on citation counts between 2007-2017 are as following; Semiconductors, Power Electronics, Data Technologies, Robotics and Mechatronics, Embedded Systems. Interestingly, the trend for Semiconductors is stronger than Power Electronics. Focal point seems to be more concentrated in this area considering cross-sectoral perspective. Also, it should be considered that the abovementioned sub-technology areas are expected to be related and tied, and not all separated, especially when the examination is cross-sectoral convergence.

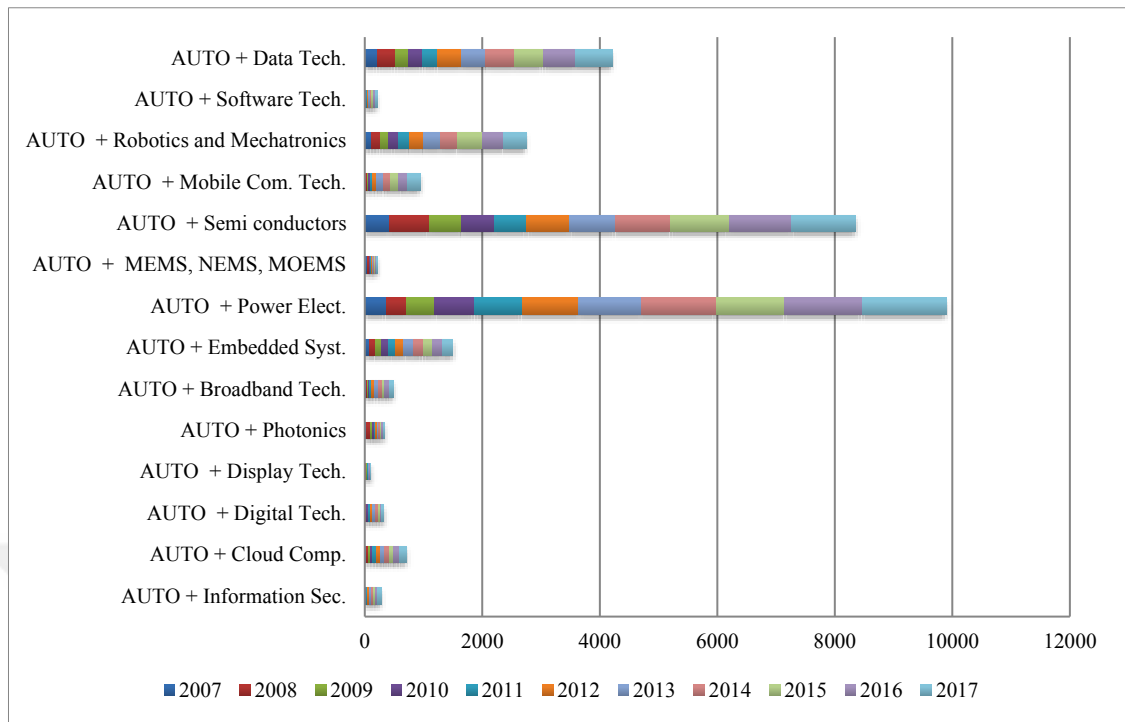


Figure 5.2. Frequency of ICT-Based AUTO TAs, Publication Counts, 2007-2017

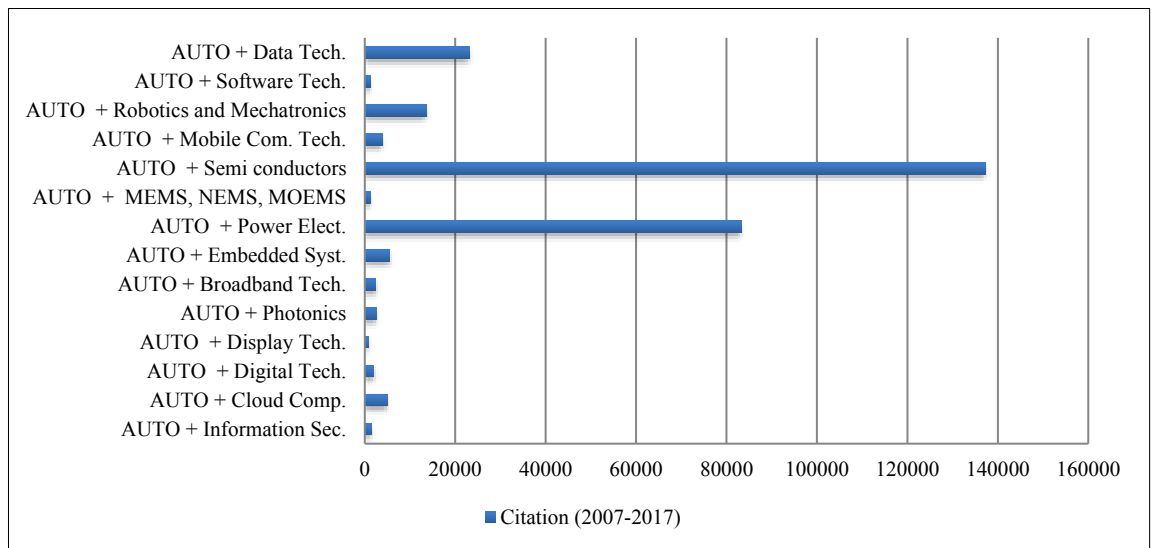


Figure 5.3. Frequency of ICT-Based AUTO TAs, Citation Counts, 2007-2017

To observe the ties and links in the cross-sectoral perspective and especially co-evolutionary interaction, network mappings are prepared. For keyword co-occurrence

mapping analysis, author keywords and full counting methods are applied, and five co-occurrences are chosen as a minimum threshold. Of the 16,561 keywords, 323 met the threshold, thirteen clusters with 290 items are obtained after the standardization process. For the normalization method, association strength is chosen. This way both prominent clusters and their linked ties are examined.

For ICT-based AUTO sector, Figure 5.4 shows keyword co-occurrence network mapping analysis by clusters. Figure 5.4 shows that electric vehicle (EV) and hybrid electric vehicle (HEV) are the most prominent nodes; following by li-on battery, energy management system, smart grid, supercapacitor, vehicle-to-grid, and modeling and simulation. Consecutively, autonomous vehicles, embedded systems, and cybersecurity nodes can be observed with relatively high co-occurrences and total link strengths within thirteen individual clusters. In relation to autonomous vehicles, nodes for automated guided vehicle systems (AGVs) and advanced driver assistance systems (ADAS) also come forward. As can be seen the nodes for smart grid and vehicle-to-grid (V2G) are highly linked with EV and HEV nodes. There is also a small but related node of grid-to-vehicle (G2V) is seen tied to V2G.

Since the recent developments of EV and HEV have accelerated innovation and improved efficiency in electric motor controls, different converters, and different battery technologies, and related advanced materials as well as battery management system can also be observed having most co-occurrences. These prominent nodes already show a cross-sectoral perspective which is not surprising. Therefore, this shift in ICT-based AUTO sector is observed clearly in the mapping that how ICT plays a crucial role in AUTO sector. Also, from this shift, obvious KETs are observed that are forming cross-sectoral convergence. This shift can be observed more with the node of autonomous vehicles besides EV and HEV, especially with related links with the nodes of connected vehicles, wireless communication, cyber-physical systems, sensors, neural networks, IoT, V2V, V2I, V2X, AI, and ML (predictive control, intelligent control, etc.); which are all cutting-edge technologies for ICT-based AUTO sector. Additionally, there is a strong link between autonomous vehicles and intelligent transportation systems. Moreover, it should be noted that these results are full in

correlation with the abovementioned prominent sub-technology areas from Figure 5.2 and Figure 5.3, respectively. However, with mapping, it is also observed that how significant sub-technology areas are transforming and becoming KETs (which are also separately becoming converging industries). To elaborate more, it is clearly observed that ICT-based AUTO sector is formed mostly by Power Electronics, Semiconductors, Data Technologies, Robotics and Mechatronics, Embedded Systems, Mobile Communication Technologies sub-technology areas; where they form EV, HEV, autonomous vehicles as KETs; including their interaction with other related KETs; such as li-on battery, cyber-physical systems, IoT, automotive embedded systems, V2V, V2G, V2X, etc.

Moreover, Figure 5.5 shows overlay visualization of co-occurrence mapping analysis by timeline-based clusters between 2007-2017. Which also shows yearly convergence in a cross-sectoral perspective. For ICT-based AUTO sector, the main convergence seems to evolve from HEV to EV, and then to autonomous vehicles, and related sub-technology areas such as IoT, V2V, V2X, 5G, and cyber-physical systems, etc. Therefore, there is a strong interlink between HEV and cyber-physical systems. Moreover, EV, smart grid, V2G, G2V, li-on battery, and wireless power transfer related KETs (such as wireless chargers) seem to be co-evolving in the same timeline. The aforementioned results are in correlation with the abovementioned results in Figure 5.4.

Furthermore, in Figure 5.6 overlay visualization by total link strength and average citations between 2007-2017 is shown. This figure shows a reverse perspective than Figure 5.5, that unlike timeline-based clusters in Figure 5.5, total link strength for latest converging technologies (KETs) in the automotive sector, such as autonomous vehicle, cyber-physical systems, and related technologies such as V2V, V2X, IoT, ADAS, AGVs; are still new to get citations while respectively older technologies are getting more citations. On the other hand, newer technologies in supercapacitor, energy storage, and battery technologies, such as li-on battery and fuel cells, are more cited and show stronger links. These results, however, do not change the main observation elaborated above.

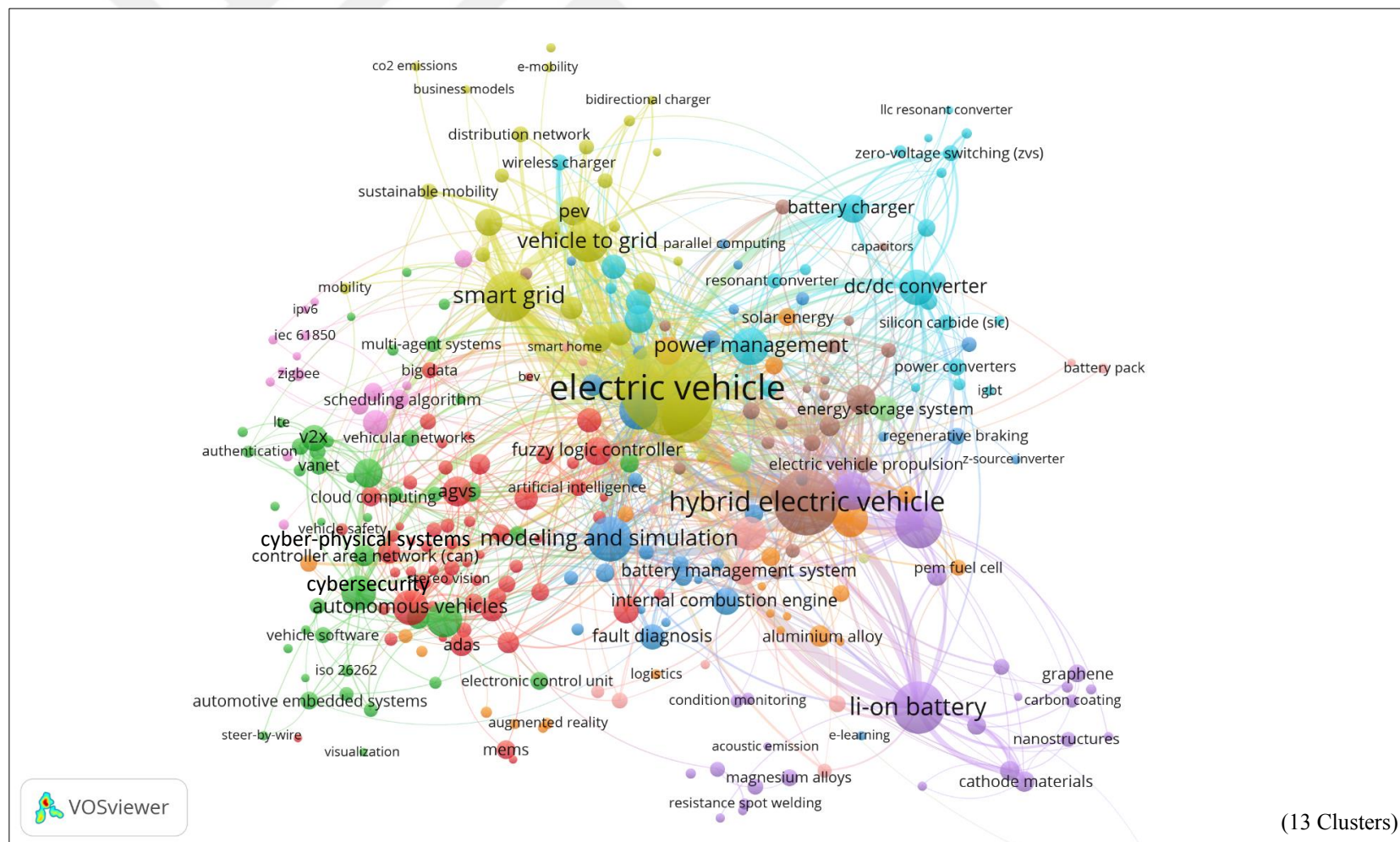


Figure 5.4. ICT-Based AUTO, Network Visualization of Co-occurrence Mapping



Figure 5.5. ICT-Based AUTO, Timeline-Based Overlay Visualization of Co-occurrence Mapping, 2007-2017

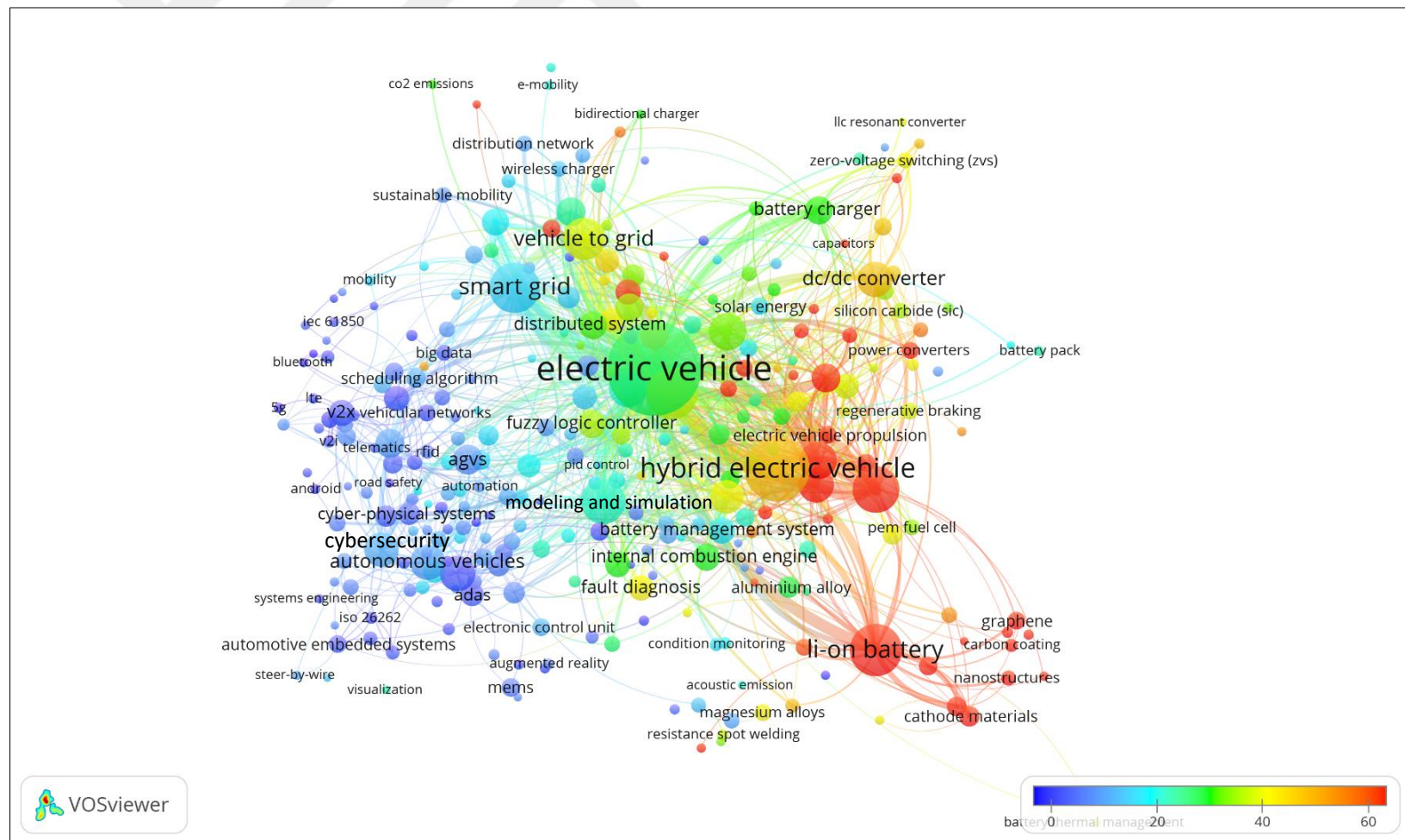


Figure 5.6. ICT-Based AUTO, Overlay Visualization of Co-occurrence Mapping with Avg. Citations, 2007-2017

Moreover, it should be noted that from all mapping visualizations, cutting-edge KETs, such as artificial intelligence, machine learning, neural network, and related KETs, are also observed closely tied with emerging converging industries in the cross-sectoral perspective.

On the other hand, it should also be emphasized that cross-sectoral convergence besides AUTO and ICT sectors can also be observed. For instance, nodes such as additive manufacturing, which are also closely related to manufacturing and materials sectors. Most importantly, there is a close relation with Industry 4.0 as well. Also, other than V2G, G2V and smart grid; energy storage system, wireless charging, fuel cell, fuel cell electric vehicle, etc. KETs can be observed, which are also closely related to the energy sector.

Lastly, to determine the countries for the same analysis, to see which are focusing on AUTO and ICT cross-sectoral approach, top countries with most publications per each sub-technology area are examined and shown in Figure 5.7. From the figure, dominance by USA and China in particular; and Germany, Japan, and South Korea as the following can be observed.

Accordingly, the top five affiliations based on publications are also examined. The dominance of countries from Figure 5.7 can also be seen within the top affiliations. However, the top five affiliations of the same analysis per each sub-technology area show another interesting point of view, that the shift of knowledge-base is seen more clearly with the examination of affiliations. While dominant actors in AUTO sector, such as Ford Motor Company, General Motors, Volvo Group take place in top ten affiliations, with also universities in AUTO sector especially those are Germany based, such as Technical University of Munich; knowledge-base also seems to shift towards:

- (1) ICT dominant companies, such as Hitachi, Ltd.,
- (2) Or, towards ICT specific multidisciplinary universities and research institutes, such as California Institute of Technology of USA, Chinese Academy of Sciences, Institute for Infocomm Research, A*Star of Singapore, Industrial Technology Research Institute of Taiwan,

- (3) Or, towards ICT specific institutes, such as IEEE,
- (4) Or, towards ICT related specific multidisciplinary research institutes, such as Argonne National Laboratory (energy, environment, national security) or Jet Propulsion Laboratory, Caltech & NASA (robotic space exploration).

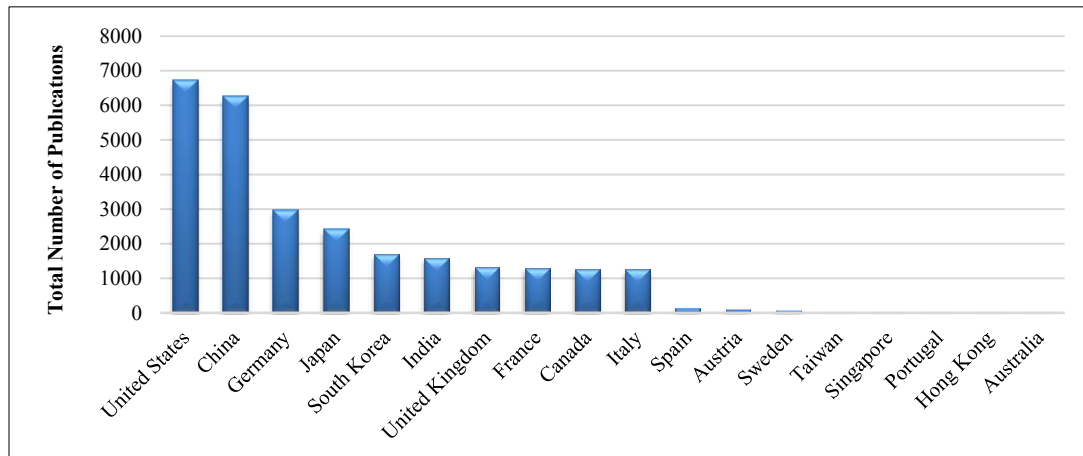


Figure 5.7. ICT-Based AUTO, Countries for Cross-Sectoral Analysis

These results also suggest that dominant actors of AUTO sector are converging with dominant actors of ICT sector, which can also be regarded as co-evolutionary. Because it is evident that even with the shift of knowledge-base, the dynamics of AUTO sector innovation system is already transforming towards dynamics of ICT sector innovation system, and vice-versa; that consecutively triggers other dynamics as well. However, to examine the co-evolution aspect more, results of analysis of AUTO-based ICT sector should be investigated further; which is given below.

For AUTO-based ICT sector, sub-technology areas becoming more frequent in the automotive based ICT sector between 2007-2017 keyword bibliometric analysis is given below in Figure 5.8. According to the figure, it can be seen that the foremost sub-technology area for AUTO-based ICT sector is Electric and Hybrid Vehicles (EHV). This result is expected, as well as in total accordance with the abovementioned results for ICT-based AUTO sector. Following sub-technology areas that are also showing concentration; such as Engine and Engine Transmission Components, AUTO Embedded Systems, and

AUTO Battery Technologies, are also in accordance with the abovementioned analysis results for ICT-based AUTO sector. This observation also suggests that the main components of AUTO sector are increasingly becoming the main components of ICT sector. Additionally, when looking at the annual distribution of the sub-technology areas mentioned above based on publications; it is seen that EHV is increasing at an increasing rate on an annual basis as well, while others are showing a constant yet slightly increasing trend. EHV sub-technology area becoming the main focal area of AUTO-based ICT sector, while suggesting that there is a trending need for, for example, improving energy efficiency, improving the reliability of electrical motors, escalating performance requirements by microcontrollers (MCUs), etc. that are also becoming more and more dependent on ICT sector. In other words, it can also be suggested that while AUTO sector is transforming by the dynamics of ICT sector, this transformation is not one-sided. The observation of the lower but constant annual increase of Engine and Engine Transmission Components, AUTO Embedded Systems, and AUTO Battery Technologies that is shown in Figure 5.8, also supports the two-sided transformation between two dominant sectors.

Accordingly, sub-technology areas cited frequently between 2007-2017 in ICT sector based on automotive sector keyword bibliometric analysis are given below in Figure 5.9. Correspondingly with Figure 5.8, EHV is seen as the foremost sub-technology area regarding citations while examining AUTO-based ICT sector. On the other hand, based on citation analysis it can be suggested that following the Engine and Engine Transmission Components sub-technology area, AUTO Battery Technologies are becoming the focal area of AUTO-based ICT sector, in contrast with publication based analysis. This result is also in correlation with the development of EHV, which accelerated innovation and the need for improved efficiency in battery management systems and technologies.

While not prominent as the abovementioned sub-technology areas, AUTO Material Technologies can also be seen at the front, both from Figure 5.8 and Figure 5.9. Regarding the improvements and future trends of the material technologies for AUTO components, this result of decreasing annual trend and lower volume of citations can be stated as in contrast to the AUTO sector dynamics. However, from the cross-sectoral perspective, this

result is regarded as expected. Because, the main developments of material technologies for AUTO sector show the increasing use of light materials, high strength steel, nanostructures, smart materials. Additionally, main drivers are mostly linked to technical requirements; such as the reduction of fuel consumption, cost out, environment regulations, energy diversification, etc. Which are most prominently related to Engine and Engine Transmission Components and AUTO Battery Technologies, which are already showing an increasing trend.

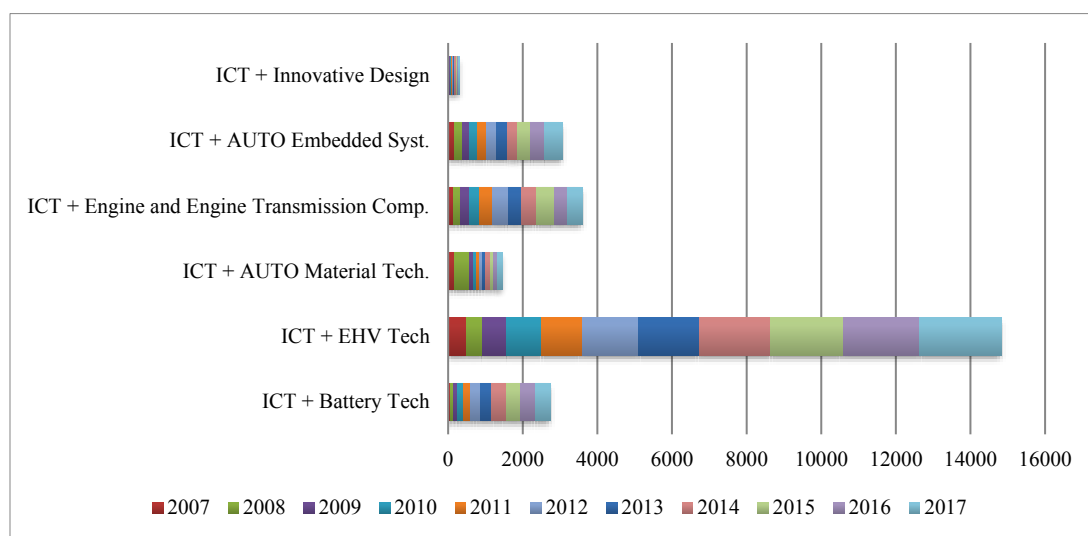


Figure 5.8. Frequency of AUTO-Based ICT TAs, Publication Counts, 2007-2017

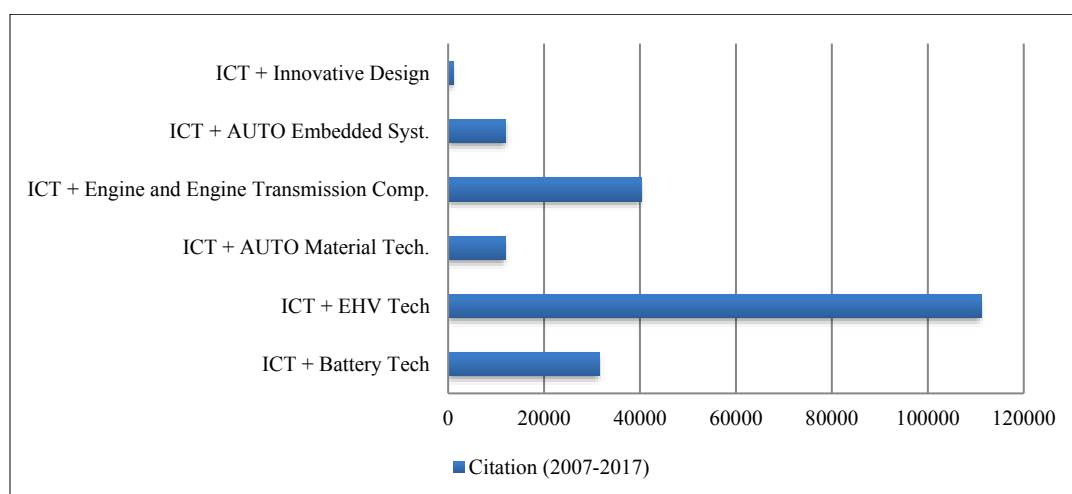


Figure 5.9. Frequency of AUTO-Based ICT TAs, Citation Counts, 2007-2017

Similarly with ICT-based AUTO sector, to observe the ties and links in the cross-sectoral perspective and especially co-evolutionary interaction, network mappings are prepared for AUTO-based ICT sector as well, which are given below. For co-occurrence mapping analysis, author keywords and full counting methods are applied, and five co-occurrences are chosen as a minimum threshold. Of the 15,400 keywords, 304 met the threshold, fourteen clusters with 283 items are obtained after the standardization process. For the normalization method, association strength is chosen. This way both prominent clusters and their linked ties are examined.

For AUTO-based ICT sector, Figure 5.10 shows network visualization of co-occurrence mapping analysis by clusters. In the figure electric vehicle (EV), hybrid electric vehicle (HEV), and plug-in electric vehicle (PHEV) seem even more dominant than the corresponding mapping for ICT-based AUTO sector. Additionally, smart grid, vehicle-to-grid, dc/dc converter, energy management system, supercapacitor, modeling and simulation, and autonomous vehicle, which is highly interlinked with embedded software and systems, are seen as main nodes within fourteen individual clusters for science convergence between two sectors. Moreover, EVs, HEVs, and PHEVs are all strongly interlinked with emerging KETs, however, autonomous vehicle node comes forward as separated with related KETs, but rather emerging KETs observed as linked via intelligent transportation system. Therefore, compared to the case shown by the analysis of ICT-based AUTO sector, EVs and related KETs are more dominant for AUTO-based ICT sector. Additionally, emerging KETs are mostly related to energy efficiency, energy storage, charging and transmission technologies related and strongly tied with EVs. For instance, supercapacitor, battery charging, and battery-related material technologies, such as silicon-carbide (SiC), li-on battery, wireless power transfer and on-board charger, state of charge (SOC), renewable energy sources (such as photovoltaics, fuel cells, etc.).

Therefore, the shift in AUTO-based ICT sector in the mapping is observed clearly comes forward as EHV and strongly tied with sub-technology areas shown as Engine and Engine Transmission Components, and AUTO Battery Technologies; which are in full correlation with the abovementioned sub-technology areas from Figure 5.8 and Figure

5.9, respectively. Accordingly, autonomous vehicle, and strongly tied KETs, such as modeling and simulation technologies, embedded software and systems, V2X are seen as prominent nodes. This result suggests a correlation with AUTO Embedded Systems sub-technology area as well. Similarly, it can be observed how prominent nodes are becoming emerging KETs and converging industries separately. Figure 5.11 shows overlay visualization of co-occurrence mapping analysis by timeline-based clusters between 2007-2017. This result also shows the main yearly cross-sectoral convergence between the two sectors. For AUTO-based ICT sector, the main convergence seems to evolve from energy storage and dc/dc converters and to EVs and on-board chargers. Also, from autonomous vehicles to related KETs such as ML, ADAS, IoT and related KETs are distinct, however mostly related to intelligent transportation systems. Furthermore, it is evident that vehicle-to-home (V2H) and wireless power transfer and related KETs are getting higher focus as the year progresses.

Lastly for co-occurrence mapping, in Figure 5.12 overlay visualization by total link strength and average citations between 2007-2017 is shown. Similarly, with ICT-based AUTO sector mappings, it shows a reverse perspective than Figure 5.11. To elaborate, unlike yearly based clusters in Figure 5.11, total link strength for latest converging technologies in ICT sector, such as autonomous vehicle, and related KETs, such as V2V, V2X, embedded software and systems are still new to get citations while respectively older technologies are getting more citations, such as HEVs and strongly interlinked power electronics, energy storage, automotive battery technologies. Additionally, AI related terms come forward, such as dynamic programming.

On the other hand, newer technologies in battery technologies such as fuel cells are getting more citations and showing stronger links, as well. Both EVs and HEVs contain batteries and can operate more efficiently than conventional gas-powered vehicles, and HEVs battery is smaller than the battery in an all-EVs, and can only support a limited range of electric driving. It is evident that the need for improving battery technologies as well as chargers triggered the need for development and innovation for HEVs, thus it is expected for HEVs in AUTO-based ICT sector to get more cited than EVs. Besides, even though the area is composed of older technologies, the integration requires the

development of newer technologies that are also already used in EVs, which are also strongly tied with power electronics, and related KETs.

Moreover, it should be emphasized that similarly to ICT-based AUTO sector, cross-sectoral convergence besides AUTO and ICT sector can also be observed. In the case of AUTO-based ICT sector, the emerging KETs are strongly linked to the energy sector, including renewable energy technologies (such as photovoltaics, wind energy, integrated with smart grid, and G2V). While related material technologies can also be observed for converters and inverters for rapid charging, such as SiC semiconductors, it can not be suggested that the materials sector is a significant part of cross-sectoral convergence, from the mappings, like it can be suggested for the energy sector. However, new material technologies in relation to the energy sector, which is strongly linked to AUTO-based ICT sector are mostly observed within the mappings which are also materials of semiconductors. For instance, the abovementioned SiC semiconductors are more energy-efficient and better at handling rapid charging. They are already widely used in newer battery technologies which are also strongly tied with PHEV charger as seen in Figure 5.12, even though the citation is not correlated with the application amount in AUTO-based ICT sector, which does not change the main observation elaborated above.



Figure 5.10. AUTO-Based ICT, Network Visualization of Co-occurrence Mapping



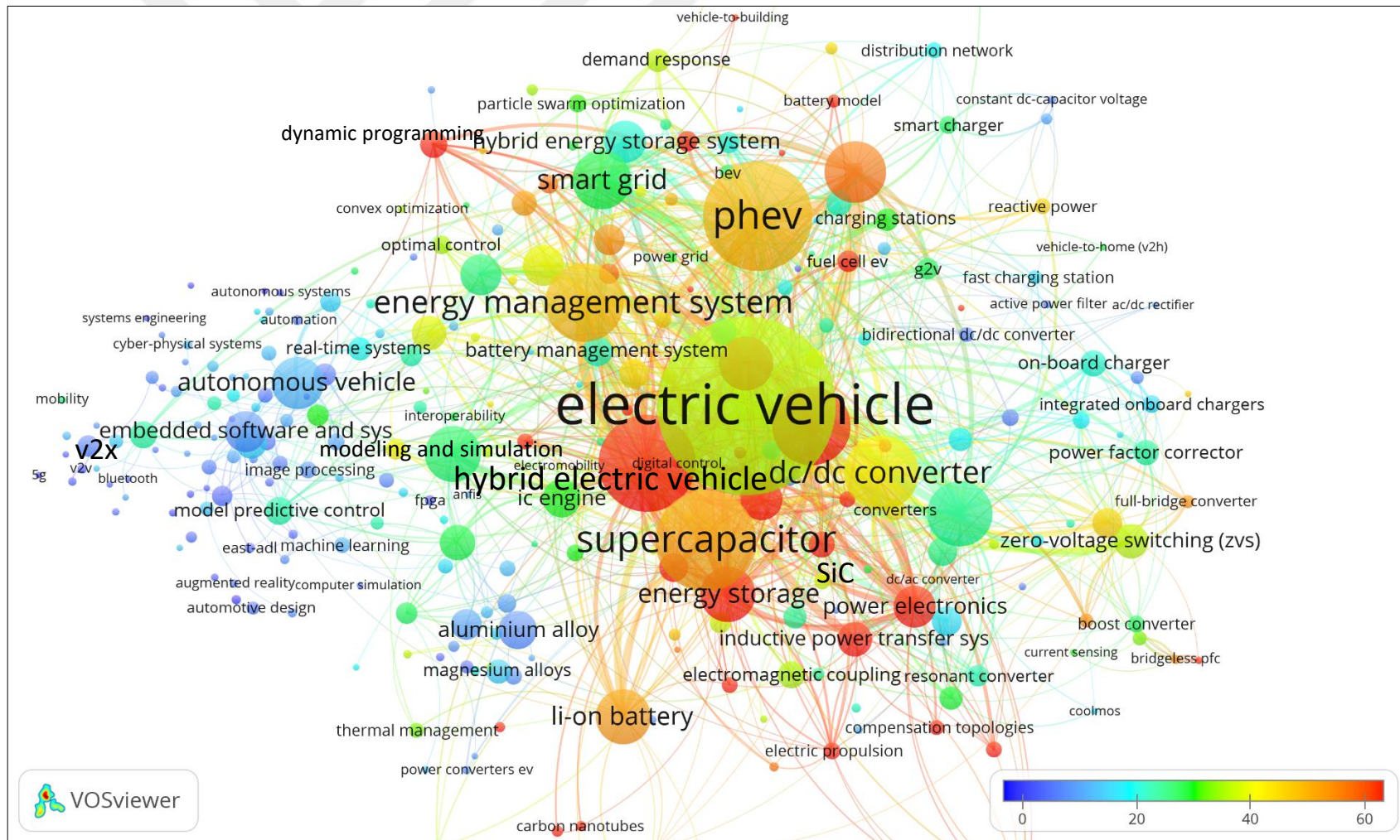


Figure 5.12. AUTO-Based ICT, Overlay Visualization of Co-occurrence Mapping with Avg. Citations, 2007-2017

Furthermore and most importantly, it should be emphasized that from all mapping visualizations, but especially from Figure 5.11, cutting-edge KETs, such as IoT, autonomous vehicle, AI and ML related terms, swarm intelligence, VANETs, and other related KETs, such as V2V, V2I, V2X, 5G can also be observed closely tied within cross-sectoral perspective. In the same context terms such as, AGVs, intelligent vehicle, connected vehicle, and intelligent transportation systems are observed. This result suggests the cross-sectoral co-evolutionary perspective from the AUTO-based ICT sector. AUTO sectoral innovation system dynamics are also transforming the dynamics of the ICT sector innovation system. For instance, specific standardization, renewable energy integration, business models, demand response can also be seen from the mapping visualizations.

Lastly, to determine the countries for the same analysis, which are focusing on AUTO and ICT cross-sectoral approach, top countries with most publications per each sub-technology area are examined and shown in Figure 5.13. It can be seen that in particular USA and China have the dominance for the AUTO-based ICT sector, while Germany, Japan, and South Korea follows. This result is the same as ICT-based AUTO shown in Figure 5.7, above. While the dominant countries and the order match, the case for Germany could be expected to be more dominant for the AUTO-based ICT sector, rather than ICT-based AUTO sector. It can be suggested that this difference surfaced because of the cross-sectoral perspective.

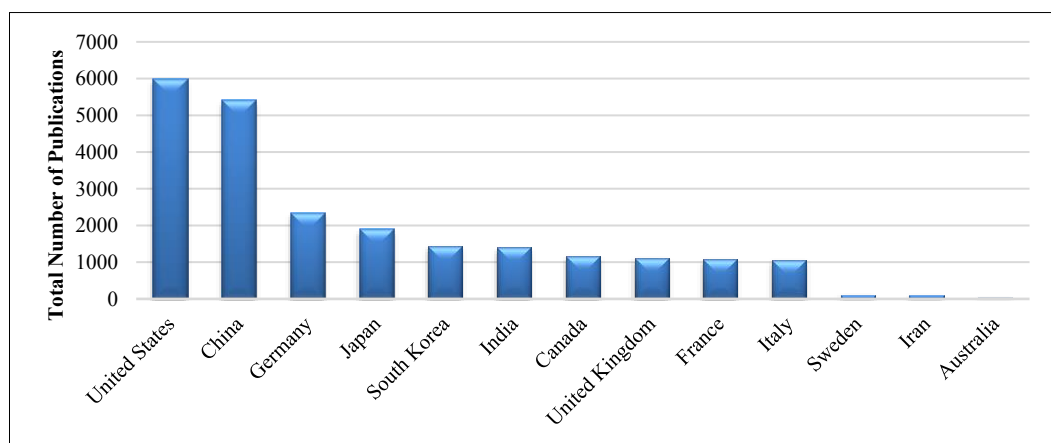


Figure 5.13. AUTO-Based ICT, Countries for Cross-Sectoral Analysis

Accordingly, the top five affiliations of the same analysis per each sub-technology area are examined, which shows a corresponding result as ICT-based AUTO sector as well. For AUTO-based ICT sector, while ICT specific multidisciplinary and interdisciplinary universities and research institutes, such as California Institute of Technology of USA, Chinese Academy of Sciences take place in the top five affiliations, knowledge-base also seems to shift towards:

- (1) Dominant actors in AUTO sector; such as General Motors, Ford Motor Company, and Daimler AG,
- (2) Or, towards ICT related specific multidisciplinary and interdisciplinary research institutes, such as Argonne National Laboratory (energy, environment, national security) or Jet Propulsion Laboratory, Caltech & NASA (robotic space exploration).

To elaborate the results, AUTO-based ICT sector bibliometric analysis based on scientific publications also suggests that dominant actors of the ICT sector are converging with dominant actors of the automotive sector. While there is also a dominance by ICT specific and ICT related multi- and interdisciplinary research, which is closely related to cross-sectoral convergence. Significantly, co-evolutionary aspects can also be suggested. That the dynamics of ICT sector innovation system is also transforming towards dynamics of AUTO sector innovation system, this means that knowledge-base of the AUTO sector is shifting towards scientific research (multi-, and/or interdisciplinary), when AUTO-ICT cross-sectoral convergence is concerned. For instance, by looking at the overall affiliations (without taking any order) there is a huge share of universities and research institutes in all of the sub-technology areas. In contrast to this finding, for some of the sub-technology areas, private sector based knowledge-base is also observed. For instance, for ICT + AUTO Material Technologies, ICT + AUTO Embedded Systems and ICT + Innovative Design sub-technology areas, more involvement of automotive sector dominant actors is seen (mainly Ford Motor Company, General Motors, BMW, AUDI AG, Volvo, Nissan Motor Co., Ltd., and Renault). It can be suggested that both knowledge and technology-bases (as well as demand-driven aspects) are in close interaction regarding

the cross-sectoral perspective, especially between two or more than two dominant sectors are concerned.

As a result, the findings of quantitative analysis based on bibliometric analysis methods with scientific publications for science convergence for both ICT-based AUTO sector and AUTO-based ICT sector demonstrate a significant correlation with the CSIS approach. Data for Turkey is presented in Appendix E, as Section E.1 and Section E.2, respectively.

5.1.2. Quantitative Analysis for Technology Convergence

First, scope and method sub-section, then analysis results and evaluation sub-section for quantitative analysis for technology convergence are given below.

5.1.2.1. Scope and Method

Basic methodologies for measuring technology convergence are generally IPC co-classification analysis and co-citation analysis based on patents as sources. The co-word analysis method is also common, where applicable because IPC codes and sub-technology areas/keywords concordance is challenging (Table 4.2, Jeong et al., 2015, p.846). As aforementioned in Chapter 4, bibliometric analysis using patents is still an experimental and developing area. In this section, cross-sectoral matching analysis method is applied using sub-technology areas composed of keywords via co-word analysis using retrieved data from the Derwent Database, only using patent publications. Derwent Database includes the most extended patent databases such as WIPO, USPTO, EPO, and JPO. Moreover, it offers a Derwent World Patent Index (DWPI)⁶ Manual Codes, which is a hierarchical indexing system, intended for use as a patent retrieval and analysis tool. DWPI categorizes patents using a classification

⁶ Note 1: DWPI is used with standard titles which are; Publication Number, Title, Title DWPI, Publication Date, IPC-Current, IPC DWPI, IPC 4 Character Sub-Classification, Abstract (English), Assignee, Claims Count and Count of Citing Patents.

system for all sub-technology areas, thus it allows analyzing patents by using sub-technology areas and/or keywords related to IPC codes. Therefore, sub-technology areas and keyword clusters could be used for patent analysis as well.

There are a few limitations and assumptions for the analysis. First, since the patent data is retrieved from Derwent Database, retrieval limitations and coding requirements of the aforementioned database are considered while analyzing the data. As a result, cross-sectoral matching analysis method had to be modified and differentiated from bibliometric analysis coding based on scientific publications presented in Section 5.1.1. Conjunction of sector clusters for the cross-sectoral matching analysis is developed and used. To explain, six sub-technology areas and their keyword clusters under the automotive (AUTO) sector, and fourteen sub-technology areas and their keyword clusters under the ICT sector are standardized into main clusters for both sectors. Namely, an **AUTO-ICT sector keyword cluster** is developed using existing keyword clusters.

For ICT sector, all fourteen sub-technology areas are used, but standardized into basic determinative keyword clusters for each sub-technology area, demonstrated as {ICT_TA1-14_AKC}. **For AUTO sector**, standardized determinative keyword clusters were not usable for the coding of the Derwent Database. Hence, additionally, a different narrowing down process is also needed to eliminate the miscoding and retrieval challenges. Therefore, four standard sub-technology areas and keyword clusters are determined which are considered as defining for AUTO sector in the cross-sectoral perspective of this case study. These are “electric vehicle*”, “automo*”, “autonomous driv*”, and “connected cars”⁷, demonstrated as {AUTO_AKC}. By iteratively checking the coding from the Derwent Database, the combination of both standard keyword clusters is used for measurement of technology convergence between two sectors, and co-word analysis is done via matching keyword clusters for

⁷ Note 2: In bibliometric analysis coding (*) operator allows to search different forms of a root word, e.g., automo* includes all the different words which begin with “automo*” like automotive, automobile, and so on.

each sub-technology area. The conjunction is determined as **AUTO-ICT sector**, and demonstrated as {AUTO_AKC} + {ICT_TA1-14_AKC}⁸. AUTO-ICT sector coding for patents consists of almost 17 thousand words with 57 pages. Table B.2 (Appendix B) explained the coding and shows the coding example for cross-sectoral keyword matching analysis method for {AUTO_AKC} + {ICT_TA1_AKC} (which is Information Security sub-technology area for ICT, in standardized form) for a better understanding.

Secondly, for {AUTO_AKC} + {ICT_TA3_AKC}, which is Digital Technologies sub-technology area and keyword cluster, the patent data retrieval resulted as zero counts. Therefore, the aforementioned sub-technology area and keyword cluster are excluded from the analysis. However, it is shown in graphs and figures for comparison matters. It should also be noted that, while analyzing, duplications are eliminated for all of the data. Moreover, text clustering and text mining methods are conducted via VOSviewer, and partly via Semantia. Thirdly, data for the earliest and latest (2018) dates are retrieved for a wider perspective of the analysis, nevertheless, ten years of the standard timeline is used while analyzing the data. As explained in Section 5.1.1, the years between 2007-2017 are regarded as a solid timeline to observe the cross-sectoral convergence.

Moreover, the detail of citation analysis should also be explained briefly. As it is known, it is possible to identify the influence of particular patents or particular sets of patents, and map their diffusion through the economy and investigate connections between technologies by analyzing citations. However, there are two different types of citations for patents that are counted, backward and forward citations. Backward citations are patents that are cited by the target patent, and forward citations are patents that cite the target patent. Unlike bibliographic coupling, backward citations are used to track knowledge spillovers in technology. In the cross-sectoral perspective, while

⁸ Note 3: The abovementioned process is applied for {AUTO_TA1-6_AKC} + {ICT_AKC}, however the results did not change. It should also be noted that with the double checking the risk of path-dependency is eliminated in the analysis method.

using a conjunction of keyword clusters, backward citations are also expected to show cross-sectoral spillovers and co-evolutionary aspects. For that purpose, for the citation analysis, only backward citation data is used and considered more related to the aim of this analysis.

Finally yet importantly, it should be noted that unfortunately no data for Turkey is retrieved for AUTO-ICT cross-sectoral matching analysis based on patents. In that regard, no additional retrieval and/or analysis is made for showing Turkey data; only already retrieved data is examined. Other available data can be seen in Appendix E.

Analysis parts can be summarized as follows. Firstly, to observe sub-technology areas that are becoming more frequent in the cross-sectoral perspective, patent counts for each sub-technology area between 2007-2017 are analyzed. This way, the focal sub-technology areas for AUTO-ICT sector based on technology convergence are shown. Secondly, countries are presented to determine the top five countries with the most patents per sub-technology. Accordingly, assignees (affiliations) per each sub-technology area are examined to show the technology convergence via institutions and private companies in the cross-sectoral perspective. This analysis, similarly with the results in Section 5.1.1, is expected to identify the dynamics of the innovation system better.

Additionally, to observe co-evolutionary aspects of these actors, knowledge spillovers, the technology convergence via backward citations of institutions and private companies per each sub-technology area are examined. Lastly, to elaborate the examination of co-evolutionary cross-sectoral perspective co-occurrence mappings are prepared. Co-occurrence mappings are conducted to show main clusters, networks, total link strengths based on citations, and timeline-based convergence for the conjunction of AUTO-ICT sector. To examine the data and conduct co-occurrence mappings via the VOSviewer, a SCOPUS Database format is prepared from the patent data. Co-occurrence for author keywords and full counting methods are applied in the following three examinations;

- (1) Network Visualization is applied with weights chosen as occurrences. Association strength is used as the normalization method for network visualization. With this analysis, cross-sectoral clustering with related ties is aimed to be examined.
- (2) Overlay Visualization is applied with weights chosen as occurrences and scores chosen as average publication year. With this analysis, the timeline of cross-sectoral convergence and co-evolutionary aspects are aimed to be examined.
- (3) Overlay Visualization is applied with weights chosen as total link strengths and scores chosen as average citations. Similar to the bullet (2) internal dynamics with their ties and emergent sub-technology areas are aimed to examine by their citation values.

Similar to co-occurrence mappings presented for Section 5.1.1, only edited versions of the co-occurrence mapping analysis are prepared. This means that text mining is applied based on abstracts, and all sub-technology areas/keywords are standardized, if applicable, to get more sound results. As noted before, exceptional cases were also taken into account when analyzing the mappings.

5.1.2.2. Analysis Results and Evaluation

For AUTO-ICT sector, sub-technology areas becoming frequent between the years 2007-2017 using keyword bibliometric analysis based on patents are given below in Figure 5.14. According to the figure, the most frequent sub-technology area is Power Electronics, similar to Figure 5.2 (bibliometric analysis for science convergence). Following sub-technology areas are Mobile Communication Technologies, Semiconductors, and MEMS, NEMS, MOEMS. This observation suggests that for AUTO-ICT sector, firstly and mostly the transformation of powertrain components (storage, transmission, power transfer, etc.) is becoming co-dependent in the cross-sectoral perspective. However, looking at the annual distribution of the sub-technology

areas, the annual increase is accelerating for Mobile Communication Technologies, while the other aforementioned sub-technology areas are showing a constant trend. From this point of view, it can easily be suggested that the technology-base for the AUTO-ICT sector has already become ICT-dependent components, while cutting-edge technologies are also emerging from the effect of AUTO + Mobile Communication Technologies convergence. On the other hand, the co-evolutionary aspects are also seen. It is expected that the subsequent parts of the analysis will be supporting this suggestion.

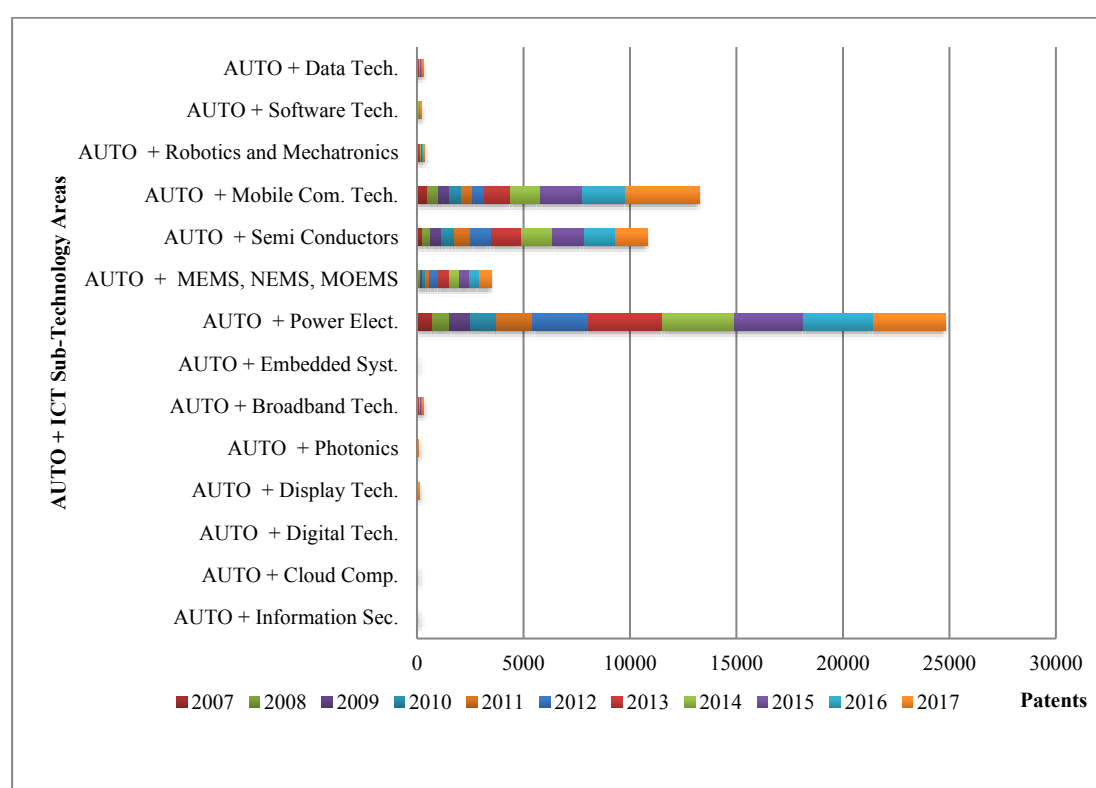


Figure 5.14. AUTO-ICT Sector, Frequency of TAs Based On Patents, 2007-2017

To determine the countries for the same analysis, to see which are focusing on AUTO-ICT cross-sectoral approach the top five countries with most patent publications per each sub-technology area are examined and shown in Figure 5.15. From the figure, dominance by Japan, China, and USA in particular, and South Korea and Germany as the followers, can be seen.

Accordingly, the top five assignees (affiliations) of the same analysis per each sub-technology area are examined (Figure C.1, Appendix C). Figure 5.16 shows the top five affiliations for the most prominent sub-technology areas, which are; Power Electronics, Semiconductors, Mobile Communication Technologies, MEMS, NEMS, MOEMS, and Robotics and Mechatronics, respectively. The dominance of the countries from Figure 5.15 can also be seen within top affiliations. Especially, the dominance of Toyota and Honda can be observed. On the other hand, the examination of the top five affiliations per each sub-technology area shows the shift of technology-base clearly. While dominant actors in AUTO sector, such as Toyota, Honda, Ford, GM, and Tesla take place in the top five affiliations, technology-base also seems to shift towards;

- (1) ICT dominant companies, such as Apple, Microsoft, IBM, LG, Samsung, and Intel,
- (2) Or, towards ICT specific multidisciplinary research institutes, such as China Electronic Power Research Institute.

More specifically, affiliations specialize under their dominant sub-technology areas and transform the corresponding sector (co-evolution). For example, under AUTO + Data Technologies dominance is by IBM, while for AUTO + Software Technologies dominance is by Tesla (an automotive-software company), for AUTO + Display Technologies dominance is by LG. These results also suggest that dominant actors of AUTO sector are converging with dominant actors of ICT sector, and vice-versa, which can also be regarded as co-evolutionary. As expected, this observation is in accordance with the suggestion made by using Figure 5.14.

Another interesting point of view can be observed from the examination of affiliations, which is technology convergence of AUTO-ICT sector sub-technology areas and its effect on the transformation of dynamics of the innovation system. For example, while the dominance for AUTO + Power Electronics and AUTO + Semiconductors sub-technology areas come forward as AUTO sector dominant actors, such as Toyota, Honda, and Nissan; there are also dominant ICT sector actors such as Panasonic and

Mitsubishi Electric. For Mitsubishi Electric another interesting point is that it is an electronic company under Mitsubishi Group along with Mitsubishi Motors, and recently specializes in information and communication systems and electronic devices for automotive equipment involving autonomous driving systems. In other words, while dominant actors of the automotive sector are specializing in the ICT sector; dominant actors of the ICT sector are specializing based on the requirements of the automotive sector, while technology-base is also merging.

On the other hand, while the dominance for AUTO + Semiconductors come forward as dominant actors of the automotive sector, the dominance for AUTO + Robotics and Mechatronics come forward as ICT dominant actors, specialized in semiconductors in particular, such as Rohm Co. Ltd., Semiconductor Energy Lab Co. Ltd. (both are based in Japan). Last but not least, as aforementioned before, the most co-evolutionary aspects in the cross-sectoral perspective can be seen by the AUTO + Mobile Communications Technologies; because the dominance for AUTO + Mobile Communication Technologies come forward as dominant actors of both AUTO and ICT sectors; which are, Samsung, Ford, Denso, Bosch, and GM.

Furthermore, the examination of the top five assignees (affiliations) of the same analysis per each sub-technology area based on backward citation data demonstrate a different perspective for the thesis (Figure C.2, Appendix C). Figure 5.17 shows the top five assignees for the most prominent sub-technology areas based on backward citation. In addition to the abovementioned most prominent sub-technology areas, Software Technologies and Data Technologies can also be observed.

From the backward citation examination, it is observed that while dominant actors in AUTO sector, such as Toyota, Honda, Nissan, Ford, TATA, Tesla, and GM take place in the top five affiliations, technology-base also seems to stay with the same dominant actors in AUTO sector while transforming their dominance in the AUTO sector. Also same as aforementioned analysis, technology-base also seems to shift towards,

- (1) ICT dominant companies, such as Apple, Microsoft, IBM, LG, and SK Planet,

(2) Or, towards AUTO-ICT sector-specific multidisciplinary research institutes, such as Shandong Academy of Sciences Institute of Automation.

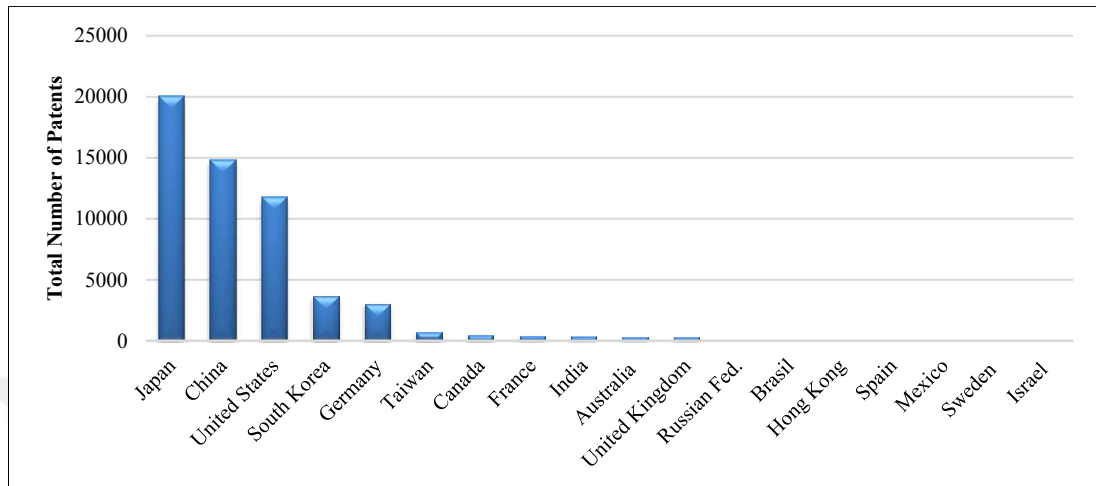


Figure 5.15. AUTO-ICT Sector, Countries for Cross-Sectoral Analysis Based On Patents

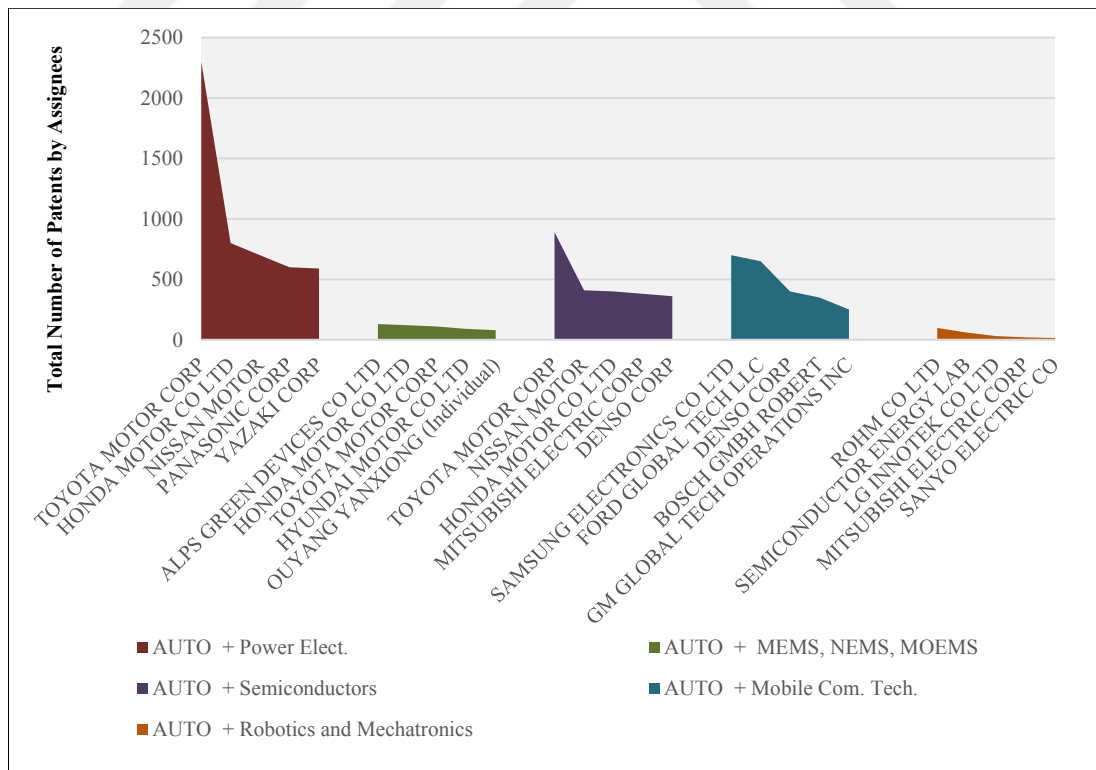


Figure 5.16. AUTO-ICT Sector, Top 5 Assignees for the Most Prominent TAs for Cross-Sectoral Analysis Based On Patents

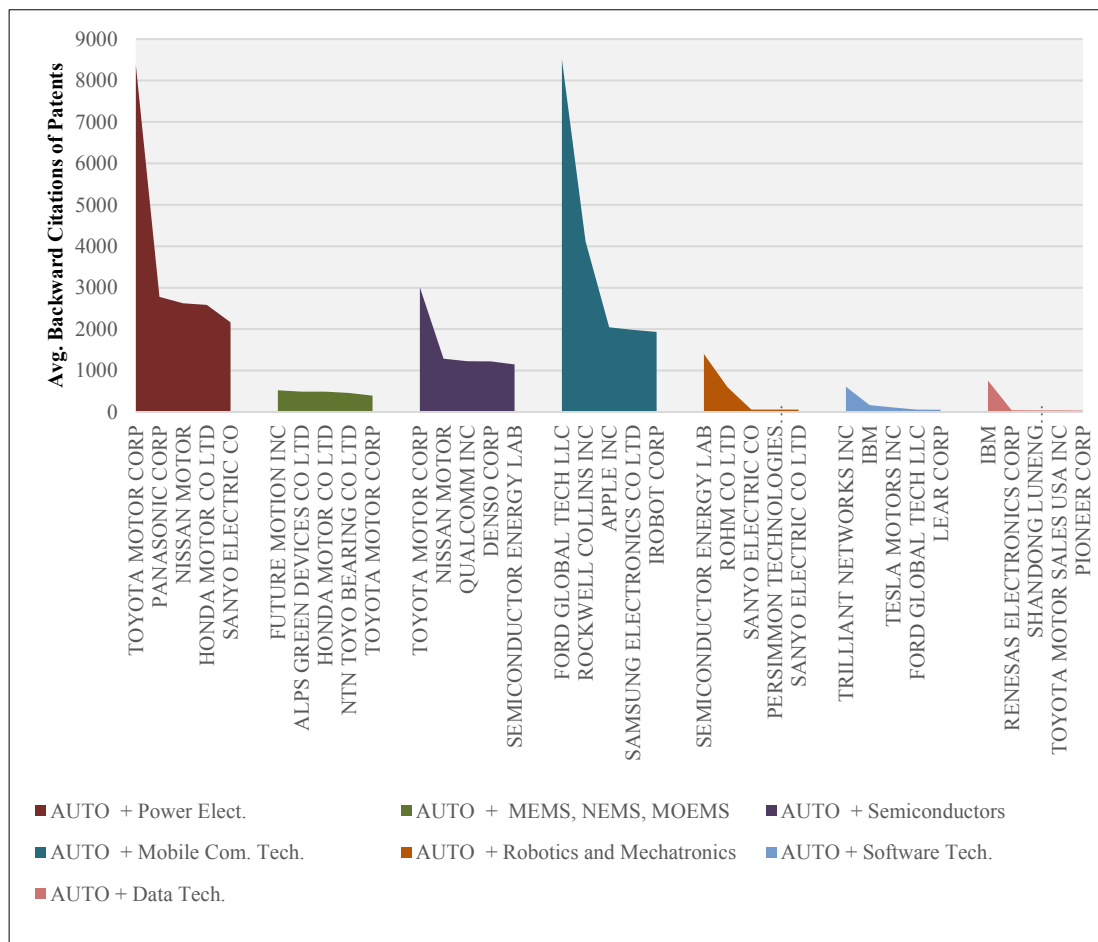


Figure 5.17. AUTO-ICT Sector, Top 5 Assignees for the Most Prominent TAs for Cross-Sectoral Analysis Based On Backward Citations for Patents

To observe the ties and links in the cross-sectoral perspective and especially co-evolutionary interaction, network mappings are prepared. For co-occurrence mapping analysis, author keywords and full counting methods are applied, and five co-occurrences are chosen as a minimum threshold. Of the 21.125 keywords, 4.138 met the threshold. Network structure did not seem as strong as the network structure of co-occurrence mapping based on science convergence. However, since it is based on patent data and technology convergence, this result is considered as expected and considered as showing that the network structure is newly indurating. To examine the network structure and the ties better, the attraction value is revised to 10, where the default value is set to 2, in order to get a proper visualization that would show the ties and interactions more clearly. Figure 5.18 shows co-occurrence mapping analysis by

clusters for AUTO-ICT sector based on patent data. Storage device, secondary battery, electrode material, display technologies, communication technologies, semiconductor device, and fuel cell, are seen as main nodes for ten individual clusters for cross-sectoral convergence. From the figure, it can be suggested that AUTO-ICT sector cross-sectoral convergence is dependent on strong ties between storage and battery technologies, while ties of communication technologies are also getting stronger.

Accordingly, Figure 5.19 shows co-occurrence mapping analysis by year-based clusters between the years 2007-2017. In this case, yearly cross-sectoral convergence between the two sectors is seen, along with co-evolutionary aspects. The range of years is scaled between the years 2011-2015 to show more explicit nodes of the network. For AUTO-ICT sector, the main convergence seems to evolve from energy storage and battery technologies related terms (such as fuel cell, secondary battery, electrode material, etc.) to mainly electric vehicle, communication technologies, and mobile device related terms such as; electrical device, power transmission coil, wireless power transfer, infotainment system, wireless communication system, communication module, and communication network, wireless device, computing device. As well as, semiconductor chips and solid solution electrode material.

In addition, there is a strong link between and evolution from autonomous control to autonomous vehicle. Moreover, it is also evident that display technologies are very important. For instance, display devices, touch screens, image data, and display systems are newer evolving technologies. Moreover, battery technologies, specifically secondary battery, seem to shift towards advanced battery technologies, such as electrical device, oxide semi-conductor chips, electrode material, solid solution electrode material, and li-on batteries. While, wireless storage devices, power transfer technologies are seen as newly enduring technologies, there are no strong links to show a shift. However, as it can be expected, newer technologies are taking communication technologies as the technology-base, even with storage and battery related ones, such as wireless power transfer technologies and devices. From this point of view, it can be emphasized that in the beginning of the 2010s an energy-based co-

evolution is observed, whereas more recently communication-based co-evolution is observed.

Furthermore, in Figure 5.20 overlay visualization by total link strength and average citations between the years 2007-2017 is shown. In this case, unlike Figure 5.19 electrical vehicle, communication and mobile device related terms do have fewer citations than the others do, even though they have strong links. Thus, Figure 5.20 shows a reverse perspective than Figure 5.19. However, for technology convergence mainly ICT related sub-technology areas are seen as keeping their importance. Display technologies and related terms such as; display system, hologram, lens, graphical user interface, video system have strong links and more cited.

On the other hand, the same is true for energy storage and battery related terms such as; secondary battery and storage device, and most cited electric storage device, secondary self-resonant coil, and resonant coil. Furthermore, while electrode material and related terms are keeping their total link strength intact they are barely cited. It should be noted that from all mapping visualizations, cutting-edge KETs, such as vehicle communication and infotainment technologies (V2V, V2X, road-to-vehicle communication, mobile devices, display and data technologies, etc.), wireless power technologies, sensors are also observed closely tied with emerging cross-sectoral perspective.

From the abovementioned analysis results and evaluation, much like to quantitative analysis of science convergence, it is evident that there is also a shift of technology-base in the cross-sectoral perspective. The dynamics of AUTO sector innovation system are transforming towards the dynamics of the ICT sector innovation system, and vice-versa, which also suggests that this transformation is co-evolutionary.

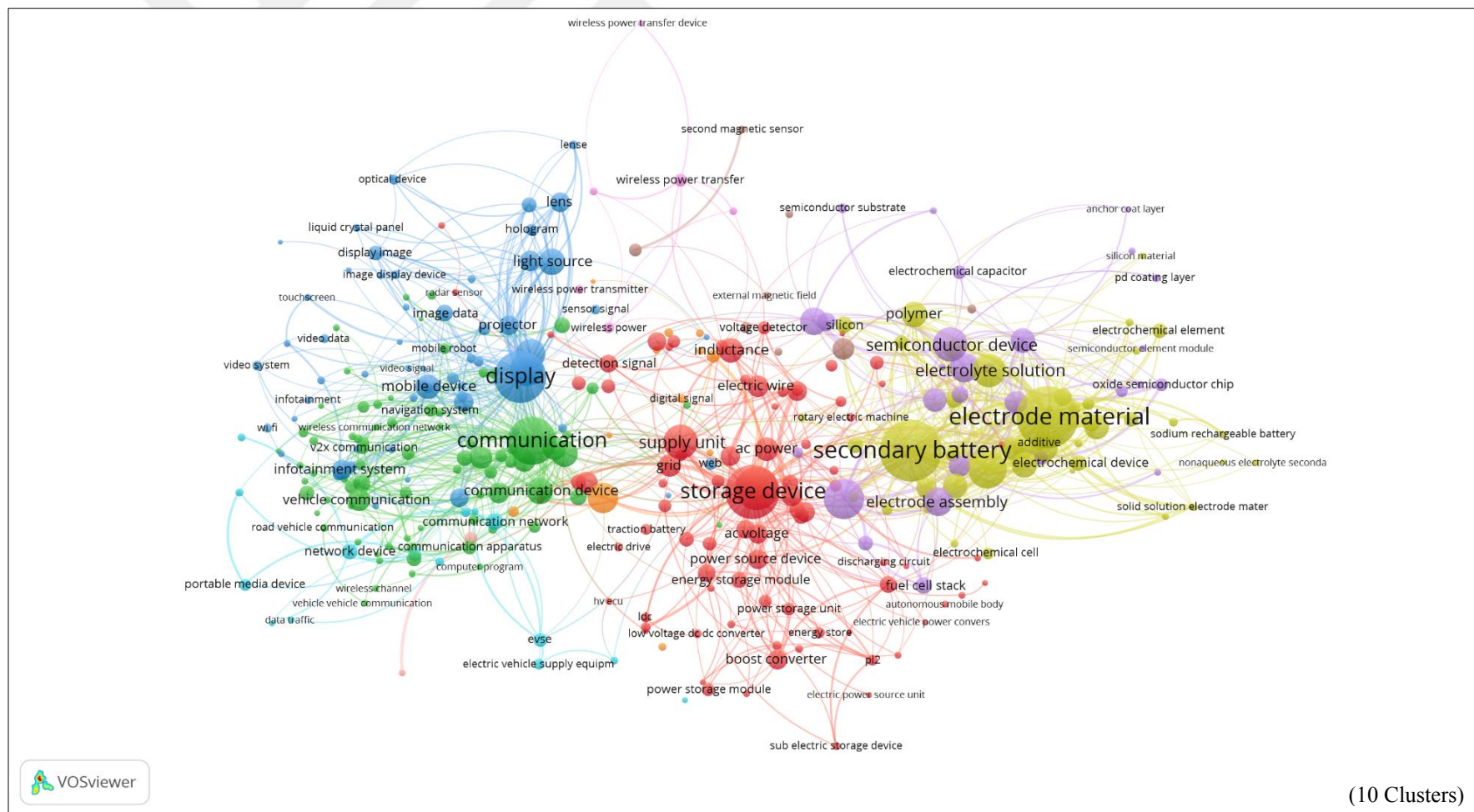


Figure 5.18. AUTO-ICT Sector, Network Visualization of Co-occurrence Mapping of Patents

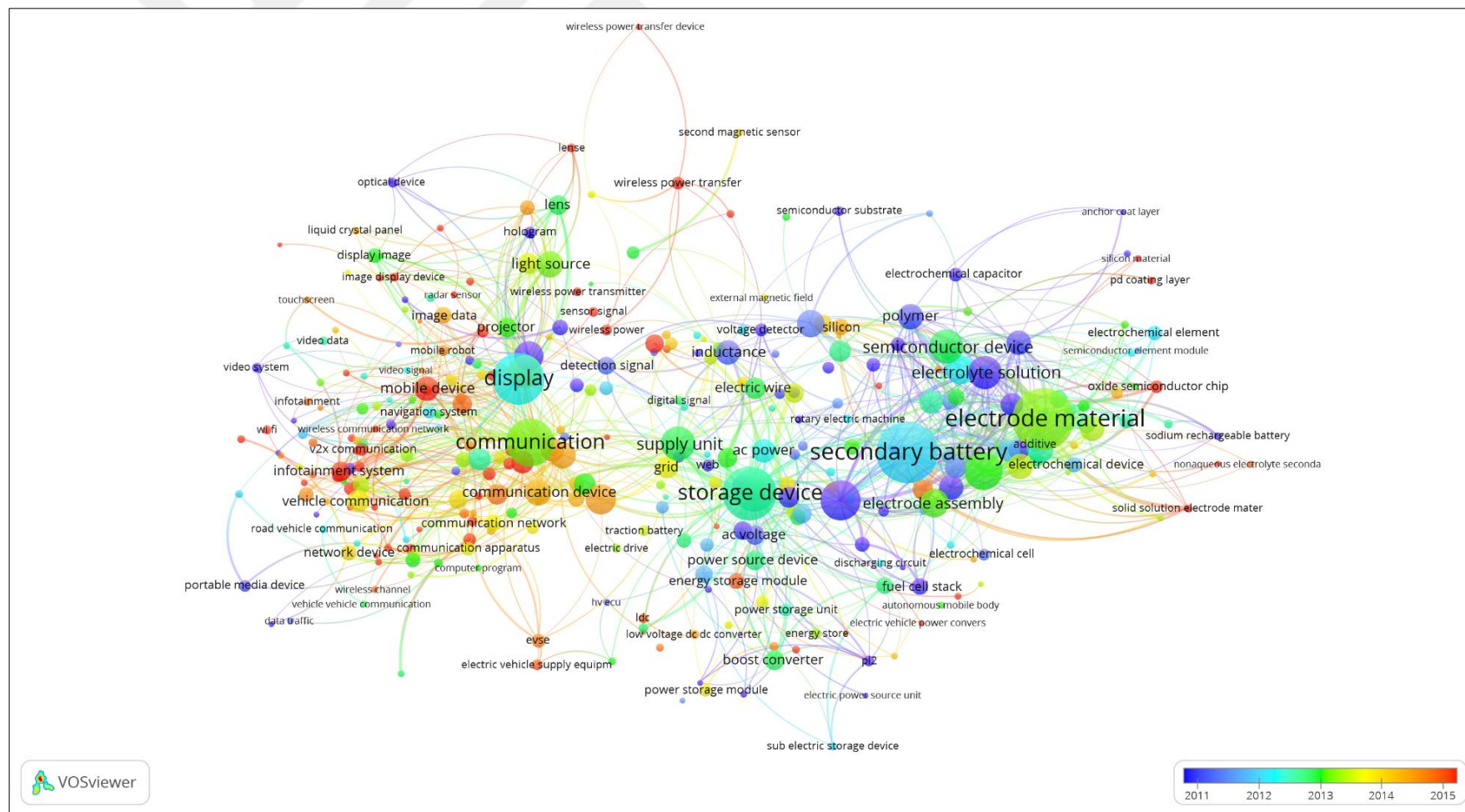


Figure 5.19. AUTO-ICT Sector, Timeline-Based Overlay Visualization of Co-occurrence Mapping, 2007-2017

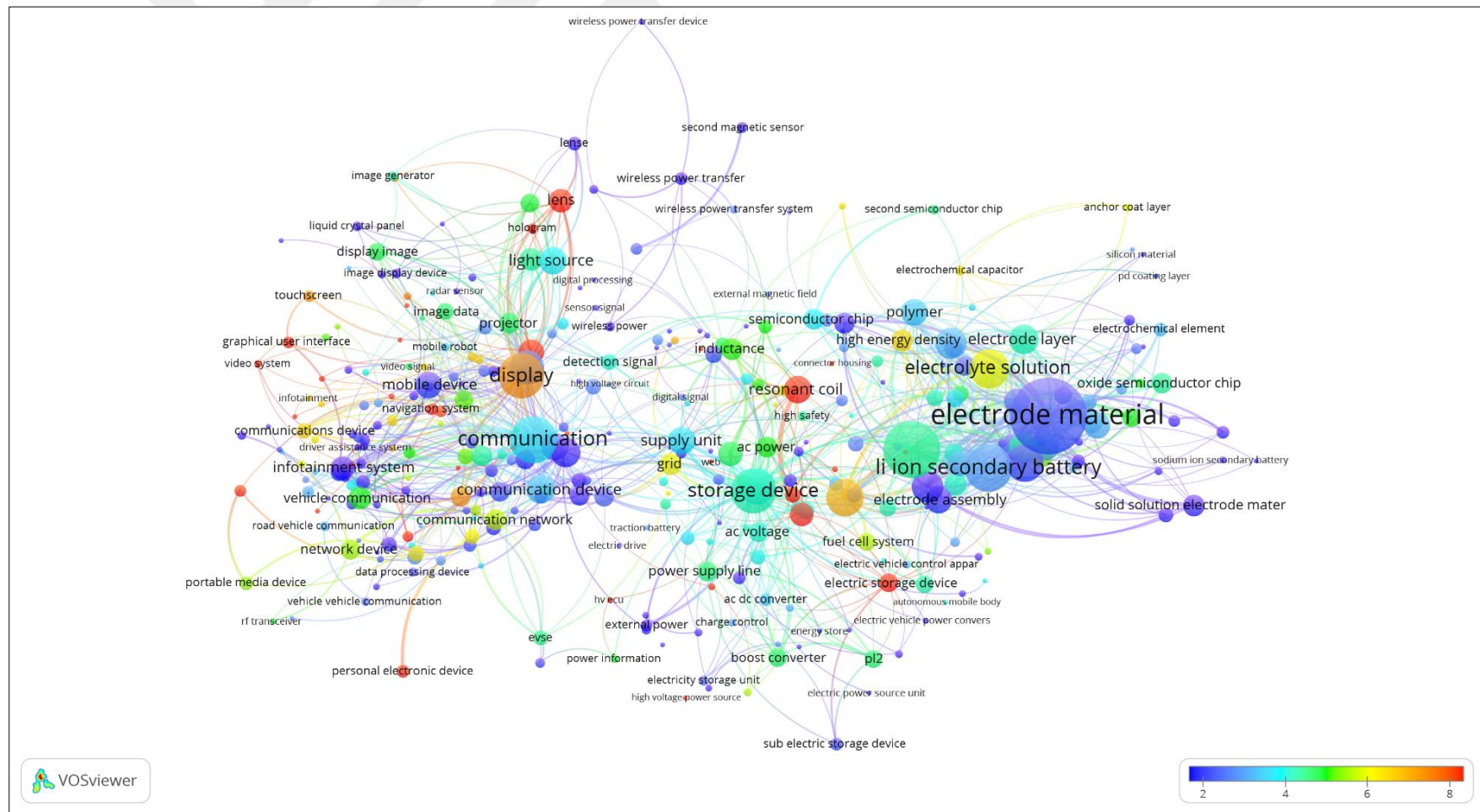


Figure 5.20. AUTO-ICT Sector, Overlay Visualization of Co-occurrence Mapping with Avg. Citations, 2007-2017

5.1.3. Quantitative Analysis for Market Convergence

First, scope and method then analysis results and evaluation sub-sections for quantitative analysis for market convergence are given below.

5.1.3.1. Scope and Method

The most frequent basic methodology for measuring market convergence is product specification analysis based on press releases (including RDI strategies, project and product news of the related companies, organizations, and/or countries via websites, social media, etc.). Newer methodologies also include tracking investments (including start-up venture capital investments, merging, private sector R&D funding, etc.). For this matter, global trend analysis using strategies of main actors in automotive and ICT sectors are examined mainly in two steps, after determining dominant countries and companies for both sectors separately. As a method, cross-sectoral matching analyses based on sub-technology areas (keyword clusters) and KETs, which are explained in previous sub-sections, are used to determine if the domain sector of the examined countries or the examined companies are converging and/or co-evolving.

As the first step, cross-sectoral matching analysis based on trends of national RDI strategies, specific landmark projects, national and/or international initiatives, and support mechanisms of dominant countries for automotive and ICT sectors are researched and examined. Moreover, their competitiveness in automotive and ICT sectors with regard to the findings of cross-sectoral matching analyses on bibliometric data. **As the second step**, cross-sectoral matching analysis is held based on trends from reports, technology roadmaps, investment strategies, and specific projects of dominant companies for automotive and ICT sectors. This way cross-sectoral co-evolution aspect of both sectors is expected to observe, driven by market convergence.

For the determination of dominant countries and companies for automotive and ICT sectors, first of all, findings of bibliometric analyses based on scientific publications and patents, which are presented in previous sub-sections (Section 5.1.1 and Section

5.1.2), are considered. Countries and companies which showed cross-sectoral convergence between automotive and ICT sectors are selected. Moreover, country and company vice R&D and innovation performances by global indexes (Global Innovation Index 2017-2018, Global Competitiveness Index 2017-2018, The 2018 Global Innovation 1000 study) are also considered to validate the results of bibliometric analyses, that whether a country or company under focus is a dominant actor or not for the selected sectors. Examination of the abovementioned indexes is given in Appendix D, as Table D.1, Table D.2, and Table D.3, respectively.

As a result, ten dominant countries are determined and examined as the following; USA, China, Germany, Japan, UK, South Korea, Canada, France, Singapore, and Taiwan. Accordingly, ten dominant companies are determined and examined, which are; Google LLC (Alphabet Inc.), Microsoft Corporation, Apple Inc., Siemens AG, General Motor Company (GM), Continental AG, Ford Motor Company, Volkswagen Group (VW), Toyota Motor Corporation, and Tesla Inc. During the research and examination of determined companies, other companies are mentioned as well according to their relations with the examined companies. The available information and secondary data for Turkey are presented in Appendix E, as Section E.3. Nevertheless, studies and reports of international organizations, such as OECD, MGI, Deloitte, are also researched to gather the general notion of the global market trends (including market convergence) in the cross-sectoral perspective. Therefore, the organization of this section is as follows, first analysis results and evaluation is presented as Section 5.1.3.2, continued with the details of the aforementioned examinations, cross-sectoral matching analyses based on global market trends (Section 5.1.3.3), determined countries (Section 5.1.3.4) and determined companies (Section 5.1.3.5), respectively.

5.1.3.2. Analysis Results and Evaluation

First of all, secondary data of international organizations are examined in order to observe disruptive cross-sectoral global market trends based on convergence. For that

matter, international organizations such as OECD, MGI, JRC-IPTS, McKinsey & Company, DETECON Consulting, CAR Group, SMMT and Frost & Sullivan, and Deloitte reports are examined. It is observed that the fast development of connectivity, autonomous driving, smart mobility, electric-hybrid vehicles (EHVs) and the user experience, with featuring new business models or sharing economy, disruptively transforming the automotive sector. In that regard, it can be suggested that there is an emerging AUTO-ICT sector in the global markets. Accordingly, both automotive and ICT sector dominant actors are approaching to invest and develop strategies, transform their respective markets in order to become leaders and pioneers of the emerging AUTO-ICT sector, where the market-base is also drastically shifting towards horizontally integrated from the cross-sectoral perspective, driven by convergence.

Later on, as the first step, cross-sectoral matching analysis based on trends of determined countries is examined and presented, which are USA, China, Germany, Japan, UK, South Korea, Canada, France, Singapore, and Taiwan, respectively. With this part of the analysis, it is aimed to focus on the upper structure of the market convergence, that how NIS (also RIS) is focusing on cross-sectoral approaches and transforming. In order to analyze the automotive and ICT cross-sectoral approaches of the countries, related strategies and projects are investigated. Then a scoring method of “5” or “10” is used to bring the measure to a comparable metric, which is defined as “level of focus”. The scoring is made regarding the strategic level of the content of the investigated documents. For instance, if the country has a dedicated cross-sectoral R&D and innovation strategy (a related law, a strategy document/action plan, a cross-sectoral/sector specific strategy document, a technology roadmap) that involves related sub-technology areas or cross-sectoral perspective as a nationally prioritized area and/or strategic targets for the national and international market, etc. or the country has related national initiatives (landmark projects) “level of focus” is taken as “10”. From the market convergence perspective a national market (a focused private sector), including whether they are targeting international markets and/or having cross-sectoral international collaborations, is also considered, and “level of focus” is taken as “10”. Or, whether the country has a specific support mechanism, a national lab, a specific agency for the cross-sectoral approaches, “level of focus” is taken as “5”. This

way, investigated documents are brought to a comparable measurement unit based on whether policies and initiatives are strategically dedicated to the AUTO-ICT cross-sectoral approaches or that remain general. While examining the documents, related KETs are also examined. Therefore, the “level of focus” reflects the dedication on KETs, as well.

As a result, examined countries show a higher level of focus for the AUTO-ICT cross-sectoral approaches. They have an R&D and innovation strategy that focuses or prioritizes on related cross-sectoral sub-technology areas (KETs), and/or national labs, agencies, and especially focused private sector. Trend analysis of determined countries also shows that focused KETs can be clustered as the following; *autonomous vehicles, cyber-physical systems, intelligent/connected mobility, digital technologies for transportation/automotive, unmanned vehicles, vehicle communication, advanced manufacturing, advanced vehicle technology, electro-mobility*.

Accordingly, to have a weighted understanding, the aforementioned KETs are correlated with the five most related sub-technology areas with the data of ICT-based AUTO sector from Section 5.1.1 (scientific publications) and the data of AUTO-ICT sector from Section 5.1.2 (patents). The total of publication counts and patent counts between the years 2007-2017 are calculated per the most related sub-technology area as well as per country. Figure 5.21 shows focused KETs and dedicated countries, via bubble size indicating their level of focus (total of the normalized level of focus which is scored from nationally prioritized to general support) and the total of publication and patent counts between 2007-2017 for x-axis and y-axis, respectively.

Figure 5.21 also shows that there is a cross-sectoral convergence between automotive and ICT sectors via market formation; and *autonomous vehicles, cyber-physical systems, intelligent/connected mobility, digital technologies for transportation/automotive* are seen as the most focused KETs for the examined countries. As shown in Figure 5.21, *autonomous vehicles, cyber-physical systems, and intelligent/connected mobility* are the prior KETs that examined countries are focusing on. On the other hand, level of focus is also high for *digital technologies for*

transportation/automotive (which is contextually very similar to intelligent/connected mobility). However, the total of patent and scientific publication counts are very low in the most related sub-technology areas. It can be suggested that while there is cross-sectoral convergence regarding all of the KETs, including mobility and transportation, there is also two-sided co-evolution for both sectors in the examined countries that prominent KETs are also showing.

Not only ICT is transforming AUTO sector, but also an AUTO-ICT sector is emerging. Separate markets of the dominant sectors, which are also prior sectors for the aforementioned countries, are converging via the support of upper structure (strategies, policies, institutions, regulations, standards, supports, mission-oriented initiatives, alliances, national/international cross-sectoral collaborations, etc.) and new markets (as well as sectors) are forming, such as *EHVs (electro-mobility)*, *autonomous and connected vehicles (CAVs)*, *intelligent mobility*, etc., which are also fostered by *AI, ML, big data technologies*. Evidently, this transformation is affecting the dynamics of NIS of examined countries. By prioritizing the AUTO-ICT sector and related KETs, by dedicating an agency, a law, an R&D and innovation strategy and/or a cross-sectoral strategy, launching a national initiative that involves all actors of the ecosystem in their respective roles, by cross-sectoral international cooperation, etc. especially regarding market structures and market convergence. For instance, a dominant country for AUTO sector, such as Germany, making an international collaboration with a dominant country for the ICT sector, such as Taiwan, to develop and merge its AUTO sector capacity with ICT sector infrastructure. It can be thought that these international collaborations can be for contract manufacturing as well as cheap labor; however, regarding cross-sectoral approaches that involve high-tech and interdisciplinary areas, collaborations are mostly for launching cross-sectoral R&D and production infrastructures that counterparts would benefit. While examining countries, evidently companies are researched as well because as can be expected they are not explicitly separated from the countries that they are established in. Therefore, it should be emphasized that, while Figure 5.21 is essentially presenting examined countries, it is also connectedly showing examined companies. For instance, while the level of focus is high for USA on autonomous vehicles, level of focus of USA

companies that are dominant in both automotive and ICT sectors (such as Google - Alphabet, Inc. and Ford Motor Comp.) is high on the same KETs. Instances can be varied. Nevertheless, more focus is put on companies and understanding the market structure from the perspective of the private sector, as the second step.

Consecutively as **the second step**, cross-sectoral matching analysis based on trends of determined companies and international organizations are examined, which are Google LLC, Microsoft Corp., Apple Inc., Siemens AG, General Motor Comp. (GM), Continental AG, Ford Motor Comp., Volkswagen Group (VW), Toyota Motor Corp., and Tesla Inc. While mainly aforementioned ten domain private sector actors are examined, other related domain actors also regarded (such as BMW, Daimler, Chevrolet, Audi, Volvo, Nissan, TATA and telecom companies, such as AT&T, moreover digital platforms such as Uber, etc.). Current market shares and targeted market shares are also analyzed. With this part of the analysis, it is aimed to focus on the inner structure of the market convergence, that how SIS is focusing on cross-sectoral approaches and transforming.

From the examination of trends of companies, in addition to the aforementioned KETs, *open source automobile operating systems (open platforms) and embedded software and systems* are observed as very noticeable. More significantly, there is a huge shift of dominant actors in the ICT sector towards the automotive sector. Vise-versa is also true but the level of shift is rather indurating. In other words, ICT-based AUTO sector cross-sectoral convergence and co-evolutionary effects are more obvious than AUTO-based ICT sector. For instance, ICT companies Google-Alphabet (Chavey, “Driverless Car”, 2013; Waymo, 2019), Apple (Apple Car, 2019a, 2019b), Microsoft (Qing, “Microsoft Auto”, 2013; Microsoft, 2018), Siemens (Software Car, 2012; e-car, 2018) have direct cross-sectoral R&D strategies (projects, platforms, subsidiaries, spin-offs, collaborations, etc.) for the automotive sector.

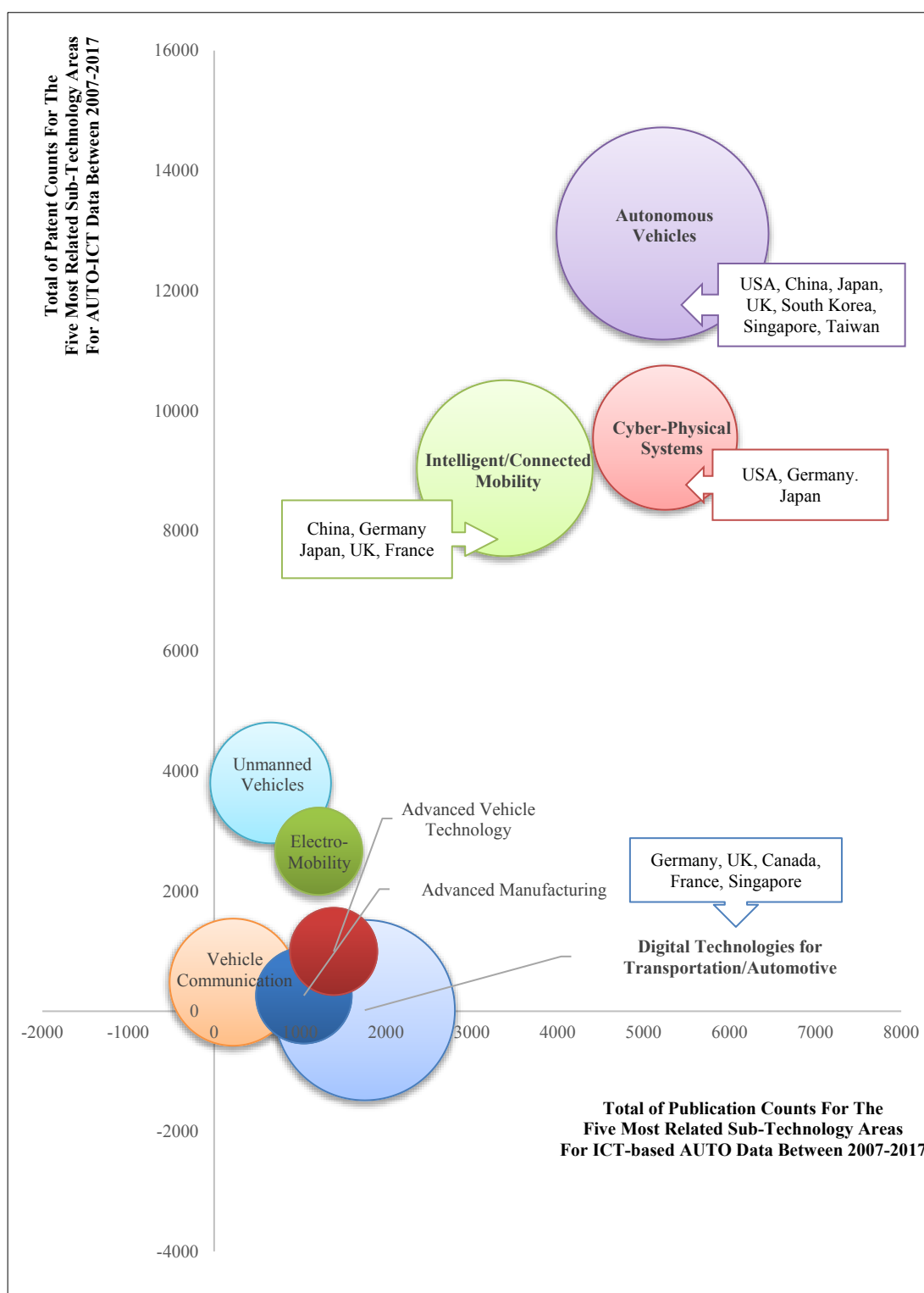


Figure 5.21. Level of Focus and Determined KETs in Cross-Sectoral Perspective for Examined Countries

However, automotive sector dominant companies indicate that their R&D strategies rather scoped as *intelligent mobility and digital transformation of transportation/automotive*. It can be suggested that this result still shows a comprehensive shift for market and technology-bases in the cross-sectoral perspective. Because, cross-sectoral national and international collaborations are very impactful; such as Google - Toyota (Driverless Cars), Microsoft - Ford (Connected Vehicle Platform, in addition to Ford, Volvo, Nissan, Harman, IAV, Toyota, Delphi, TATA, Volkswagen, and Qoros), Microsoft Automotive Sector Center in China, Microsoft - Volkswagen (Automotive Cloud), Siemens - Hyundai Motor and Uniti for digital-twins (advanced manufacturing) and e-Car (digital electric cars). Additionally, Tesla is analyzed differently as a company defining itself as a software company as well as an automaker. Recently, Tesla founded OpenAI, a research organization for advanced AI technologies, targeting level five autonomous vehicles (Tesla, 2018). Therefore, it is certain that there is a direct cross-sectoral shift from both sides. Moreover, as of 2018, Apple's CarPlay and Android's auto apps witnessed significant market growth owing to the increasing integration of infotainment platforms in vehicles. Google Android (Google Open Automotive Cross-Sectoral Alliance, 2014) and Apple iOS (Zach, 2013; Apple CarPlay, 2019). In addition, Microsoft provides Azure global scale for Apollo Open Platform Alliance with and outside of China, for the technical development and adoption of autonomous driving worldwide (Microsoft, 2018).

Furthermore, by comparing level of focus of countries and companies, a significant accordance can be seen. Companies enable cross-sectoral co-evolution regarding both technology and market convergence, shift of knowledge-base towards a technology- and market-base similar to findings of science and technology convergence analyses in Section 5.1.1 and Section 5.1.2. As a result, it can be easily suggested that there is a co-evolutionary cross-sectoral convergence for the examined countries and companies, respectively, and complementary, observed both for the upper and inner structures of market convergence. For the countries, one of the results can be emphasized as while automotive sector dominant countries show a two-sided cross-sectoral co-evolution, ICT sector dominant countries compete for the emerging AUTO-ICT sector, based on their ICT capacities. For companies, on the contrary, ICT

sector dominant companies compete to become lead actors of the emerging AUTO-ICT sector, both nationally and internationally, rather than keeping only ICT-based competitive advantages. While also, automotive sector dominant companies are quite eager to become lead actors of the emerging AUTO-ICT sector, they are also keeping their market-base as automotive sector and they mostly use alliances, platforms, collaborations with ICT sector dominant actors, etc. to compete. These dynamics of the inner structure of market convergence results as transforming dynamics of SIS and NIS, as a result. It should also be emphasized that there is a cross-sectoral co-evolution based on upper and inner structures of market convergence including other sectors, most importantly energy, materials, manufacturing, and service sectors; and the impact is disruptive with regard to the dynamics of SIS. Which is highly integrated with the dynamics of NIS, because this approach brings a cross-sectoral ecosystem perspective in holistic policymaking. For instance, standardization of energy power distribution, and demand and/or standardization of vehicle-to-grid and/or on-board charging stations are interrelated subjects.

Lastly, Table 5.1 below shows the summary of cross-sectoral matching analysis based on trends of countries regarding prioritized TAs (KETs) according to national strategies, national initiatives, cross-sectoral international co-operations, etc. of examined countries, which are also shown as “level of focus”. Table 5.2 below shows the summary of cross-sectoral matching analysis based on trends of examined companies. Both tables also present the “Direction of AUTO-ICT cross-sectoral convergence”, aiming to demonstrate whether the cross-sectoral co-evolution happens two-sided and/or one-sided for the examined country or company. Table 5.2 also shows the collaborations between examined companies, demonstrated as “C” by listing related actors by numbering, or indicating their names in the parentheses if they are other than examined firms. As the further organization of this section, primarily, cross-sectoral matching analysis based on global market trends by examining secondary data from international organizations is presented as Section 5.1.3.3. Consecutively, research remarks for cross-sectoral matching analyses based on trends of determined countries and companies are presented separately and in order, as Section 5.1.3.4 and Section 5.1.3.5, below.

Table 5.1. Summary of Cross-Sectoral Approaches for Examined Countries

Examined Countries		USA	China	Germany	Japan	UK	S. Korea	Canada	France	Singapore	Taiwan
Focus of KETs for AUTO-ICT Cross-Sectoral Convergence	Advanced Vehicles (EHV/CAV)	X	X	X	X	X	X	X		X	X
	Cyber-Physical Systems	X	X	X	X	X			X		
	Intelligent Transportation /Mobility/Electro-Mobility (incl. Energy Sector & Tech.)		X	X	X	X	X		X	X	X
	Unmanned Vehicles/Drones	X	X	X	X		X				
	Autonomous Systems (incl. 5G & IoT) M2M/V2X/AI&ML	X	X	X	X	X	X	X	X	X	X
	Advanced/Additive Manufacturing (incl. Advanced Materials)		X	X		X		X		X	
	In-Vehicle Comm./Innovative Vehicle Apps/Telematics	X	X	X	X				X		X
	Information/Cybersecurity		X		X	X		X		X	X
Dir. of AUTO-ICT Cross-Sectoral Convergence	ICT-based AUTO Sector	X	X	X	X	X	X	X	X	X	X
	AUTO-based ICT Sector	X	X	X	X	X		X			
Level of Focus via Researched Documents	RDI Strategy (incl. Dedicated Law, Technology Roadmap)	X	X	X	X	X	X	X	X	X	X
	National Prioritized Area	X	X	X	X	X	X	X	X	X	
	Sector/Cross-Sectoral Specific Strategy		X	X			X				
	National Initiative/Landmark Project	X	X	X	X	X	X		X		
	National Labs, Agencies, Focused Private Sector	X	X	X	X	X	X	X		X	X
	Cross-Sectoral International Cooperation	X	X	X			X	X		X	X
	Support Mechanisms	X	X	X		X	X	X	X		

Table 5.2. Summary of Cross-Sectoral Approaches for Examined Companies

Examined Companies		Google	Microsoft	Apple	Siemens	GM	Continental	Ford	VW	Toyota	Tesla
KETs for AUTO-ICT Cross-Sectoral Convergence	Advanced Vehicles (EHV/CAV)	X, C1, Waymo&C(FCA)	X, C2, C5	X, C(Lexus, TSMC)	X, C(TRW, AVL)	X	X, C1, C(BMW, NVIDIA)	X, C2, C5	X, C5	X, C1, C5, C(NTT)	X
	Cyber-Physical Systems	X			X	X			X	X	X
	Advanced Battery Tech.					X			X	X	X
	Intelligent Mobility (incl. Energy Sector)/Telematics		X	X	X	X	X	X	X	X	X
	Vehicle Operating Sys /Vehicle Software (incl. Open Source)	X, C3, C4, C(AUDI, Honda, Hyundai, NVIDIA)	X, C7	X, C8, C9	X	X, C3	X, C4	C7, C8	C9	C8	X
	Embedded Sys (incl. Sensors)	X		X	X			X	X	X	X
	Autonomous Sys (incl. 5G&IoT, V2X) /AI&ML	X, C(BMW, Audi, AT&T/German Telecom)	X, C6	X	X	X, C(AT&T, Amazon)			X, C6	X, C6	X
	Advanced/Additive Manufacturing (Smart Factories, Digital-Twin)		X		X	X, C(Autodesk)					X
	In-Vehicle Comm./ Infotainment	X	X, C7	X		X, C(Amazon)	X	X, C7	X	X	X
	Big Data, Cloud Computing	X	X, C6				X	C6	X, C6	X, C6	X
Dir. of AUTO-ICT Cross-Sectoral Convergence	Cybersecurity				X	X					X
	ICT-based AUTO Sector	X	X	X	X	X			X	X	X
	AUTO-based ICT Sector	X	X	X		X	X	X	X	X	X
Level of Focus via Researched Documents	RDI Strategy	X	X	X	X	X	X	X	X	X	X
	Cross-Sectoral Strategy	X	X	X	X	X	X		X	X	X
	Company Prioritized Area	X	X			X			X	X	X
	Strategic Products/ Standardization	X	X	X	X	X	X	X	X	X	X
	Cross-Sectoral R&D and Production Infrastructure	X	X		X	X		X		X	X
	Cross-Sectoral Investment	X	X	X	X	X	X	X	X	X	X
	Cross-Sectoral Collaboration (C)	X	X	X	X	X	X	X	X	X	

Note: The letter “C” demonstrates the collaborations between the examined companies by numbering in the related rows of the KETs (e.g. Google & Toyota both have “C1” at the first row, for the “Advanced Vehicles (EHV/CAV)” which means that these two companies are collaborating and for this particular KET). If the collaborated company is other than the examined ones, it is indicated with “C” and the name of the company (e.g. Waymo, one of the subsidiaries of Google, is collaborating with FCA for the “Advanced Vehicles (EHV/CAV)”. Or, Apple is in collaboration with Lexus and TSMC for the “Advanced Vehicles (EHV/CAV)”).

5.1.3.3. Cross-Sectoral Matching Analysis Based On Global Market Trends

First, cross-sectoral approaches in strategic documents and projects by international organizations are investigated to understand the cross-sectoral convergence and disruptive trends for the global market with a wider range of dominant actors of automotive and ICT sectors. International organizations such as OECD, MGI, JRC-IPTS, McKinsey & Company, DETECON Consulting, CAR Group, SMMT and Frost & Sullivan, Deloitte are investigated in particular.

As early as the 2010s, the convergence trend for ICTs across many sectors started to set the global agenda, including the automotive sector and mobility related areas. For example, according to the **OECD Information Technology Outlook 2010**, ICT is one of the multi- and interdisciplinary areas in which R&D expenditures are being directed. In that regard, featured Key Enabling Technologies (KETs) include, *traffic monitoring and control systems, personalized traffic information systems, and telematics systems*. Additionally, a **JRC-IPTS (2010)** report by the European Commission reviews the competitiveness of the European automotive embedded systems industry, as an emerging converging market and sector, and emphasizes the crucial role of ICTs in the automotive sector. The report also highlights the need for investing in KETs with software-intensive segments, such as *Advanced Driver Assistance Systems (ADAS), vehicle-to-vehicle (V2V)/vehicle-to-infrastructure (V2I) communication, and autonomous driving*.

"Think 2032! Position for ICT Everywhere" study by DETECON Consulting Company (2011), prepared in cooperation with German Telecom, emphasizes the convergence of the ICT with three main sectors of any nation, one of them being the automotive sector. Highlighted findings of the study, in terms of convergence of the automotive and ICT sectors, are shown in Figure 5.22. It is stated that the fast pace of the developments in full access to all kinds of real time information, multi-media and social network; innovators like BMW are paving the way towards *digitally connected vehicles*. The study also emphasizes ICT sector is transforming entirely that will no longer be around in 2032, as well as the sectors it most converges with, such as the

automotive sector. In this regard, the development of *cyber-physical systems (CPs)* is also highlighted. Moreover, the cross-sectoral co-evolution is emphasized, where the new sector structures are forming, including new forms of markets across sectors. Such as on-demand mobility systems, service platforms.

On the other hand, a shift from vertical disintegration to horizontal integration in the sector dynamics is observed. Standardization and opening of value chain segments (such as sales, service, network, etc.) due to regulatory pressure, IP, openAPI, are the drivers of vertical disintegration. Cross-sectoral horizontal integration emerges due to proprietary cross-sectoral value chain segments that create new markets for automotive sector dominant actors converging with the ICT sector, such as BMW Connected Drive.

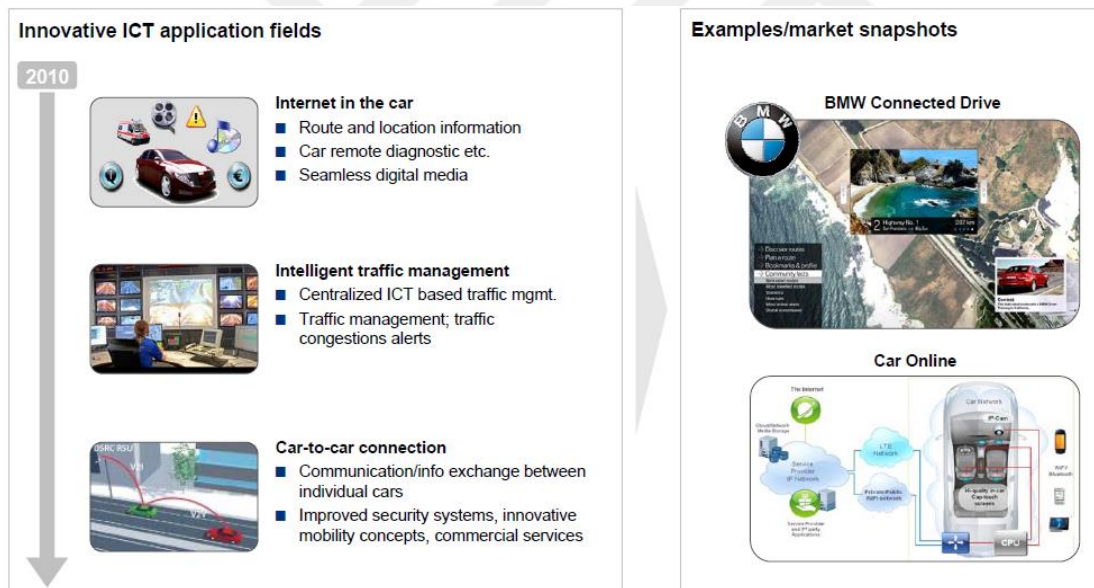


Figure 5.22. AUTO-ICT Cross-Sectoral Convergence (DETECON, 2011)

On the other hand, according to the **McKinsey Global Institute (MGI, 2013)** report, twelve disruptive technologies (KETs) and their impact on economic and social structures and other sectors are assessed from the perspective of the year 2025. *Autonomous and semi-autonomous vehicles* are reported among these KETs. While for twelve disruptive KETs, the ICT dominance is still observed, it is also stated that autonomous and semi-autonomous vehicles are disruptive as creating a completely

different automotive sector, namely an AUTO-ICT sector, that autonomous vehicles and trucks could enable a revolution in ground transportation/regulations and public acceptance permitting, by low-cost, increased safety, reduced CO₂ emissions, leisure benefits, etc. Rapid improvement of *AI*, *sensors*, and *drones* is also emphasized. These changes significantly trigger the requirements of rapid improvement in the dynamics of NIS and SIS as well, such as regulations, and standardization for KETs.

Moreover, looking from the automotive sector perspective, there are many studies that define the emerging markets dependent on ICTs, both in technology and market convergences. For instance, according to **McKinsey & Company Report, "Dimensions Affecting the Global Automotive Sector by 2020"** (2013), one of the most important dimensions that will impact the automotive sector is given as digital demands of users. In addition, by 2025, the automotive sector value chain is expected to be completely different from its current situation due to its interaction with other sectors. For example, it is stated that the primary company, including the car purchase process, is driven by digital demands. It is emphasized that this will be shaped by e-commerce technologies, as well, which would shape the basis of market formation in the cross-sectoral perspective. Apart from this, the topics that are directly related to automotive technologies, the desire of drivers to combine mobility and communication comes forward. It is stated that the development and diffusion of mobile technologies, the use of smartphones, and mobile applications for automobiles are leading the creation of a completely different sector.

According to the **"Disruptive Trends That Will Transform The Auto Industry"** (Gao, et al., 2016) and **"How The Convergence of Automotive and Tech Will Create A New Ecosystem"** (Beiker et al., 2016) reports by **McKinsey&Company** sectoral experts and actors approve that there are technology-driven trends (KETs) while reinforcing and accelerating one another that transform automotive sector entirely. Which are stated as *electrification (shift towards HEVs, full-cell technologies)*, *autonomous driving (including ADAS)*, *diverse mobility (huge effect of sharing economy and digital business models)*, and *connectivity (infotainment*

innovations, novel traffic services, and new business models and services, with wider connected infrastructure).

In the foreseen disruptive transformation of the automotive sector, vehicles are defined as computers on wheels. Which is a change similar to events in the computer sector 20+ years ago and the mobile phone sector 10+ years ago. As a result, it is anticipated that a complex ecosystem is emerging in the automotive sector. In this regard, the impact of KETs on market formation can result in a vertically integrated business model for markets, such as private or shared autonomous vehicles business models, which is both technology and market-driven cross-sectoral convergence.

With OEMs trying to keep full control of their supplier networks, the ICT sector dominant actors are observed as more focused on horizontal integration. For instance, while autonomous-driving developers from the ICT sector dominant actors are forming into vehicle software and vehicle hardware domains, there is also a huge competition for becoming a leader for developing and creating standards for *automotive operating systems* and *infotainment platforms/in-vehicle applications*. It is also noted that, no single player is likely to dominate any part of such a horizontally integrated and complex value chain by itself. Therefore, open platforms and alliances are expected to increase. Although the aforementioned four KETs have been observed for years, separately or together, they are now more than ever positioned to disrupt the automotive sector because of the overall change in the ecosystem dynamics as well, such as regulations, technology, or business models or consumer preferences. The trend and current and future enabling forces are summarized in Figure 5.23 below.

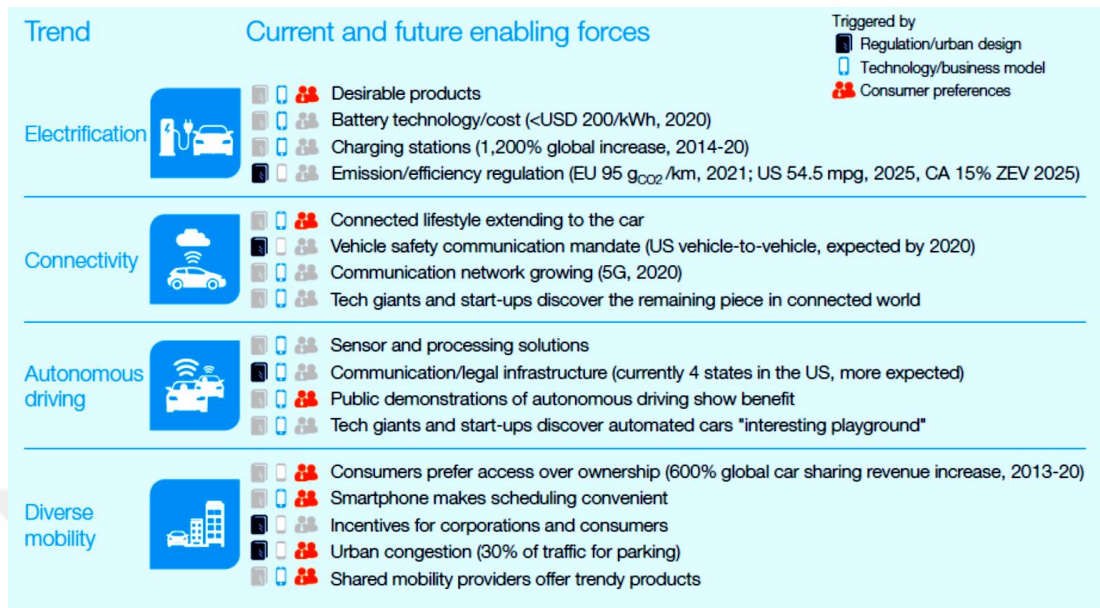


Figure 5.23. Four KETs and Current and Future Enablers in the Automotive Sector (McKinsey&Company, 2016)

To that end, the same reports lay out eight key perspectives on the “**2030 Automotive Revolution**” (McKinsey&Company, 2016) aimed at providing scenarios concerning what kind of changes are coming and how they will affect traditional automakers, suppliers, potential new players, regulators, consumers, markets, and the entire automotive sector value chain. Primarily of these key perspectives, the automotive revenue pool is expanding and focusing on on-demand mobility data-driven services. Accordingly, *connectivity*, and *later autonomous vehicle technology*, are also emphasized for their disruptive effects. For instance, communication enabled with embedded SIM cards in vehicles and cross-sectoral collaborations, such as General Motors Company (GM) & AT&T (OnStar service), BMW & German Telecom, and AT&T in USA (OECD, 2017a). BMW Connected Drive menu enables access to location-based information, such as weather and news, as well as an online search via Google (BMW, 2017). Same as Audi built-in 3G/4G mobile SIM card and Google integration in the USA. All services and information are integrated with smartphones. Audi in co-operation with German Telecom is holding trials to develop *long-term evolution for vehicles (LTE-V)*, the vehicle version of the 4G LTE, along with

dominant actors such as BMW, Toyota (Hammerschmidt, 2016; Allevin, 2016). Another example can be given from Vinli (an AUTO-based software company) that its Connected Car Adapter (Dongle) enables 4G LTE Wi-Fi hotspot and a smart device that turns any vehicle into a connected car. Scania AB, a major Swedish automaker, generates one-sixth of its revenues through new services enabled by the wireless communication technologies built into its vehicles (OECD, 2017a).

Accordingly, one of the cross-sectoral convergence aspects based on market is observed through *big-data technologies*. With the integration of *wireless communication technologies*, *IoT*, and *CPs*, the automotive sector becoming dependent on data in a drastic way. For instance, autonomous vehicles are expected to generate large amounts of data. Intel forecasts that the volume of data fully autonomous vehicles will produce 4000 GB per day by 2020, and such big-data recalls for the need for further developments in *5G*, *V2V*, *Internet Protocol version 6 (IPv6)* (Waring, 2016). For example, HERE, the Open Location Cloud Company co-owned by Audi, BMW and Daimler, aims to provide location-based data to verify and improve maps and attributes, to detect road incidents in advance. HERE also developed a universal data format for standardized vehicle data exchange, including for self-driving vehicles (Tipan, 2016; HERE, 2017). Partnerships of HERE expand through Continental, Mitsubishi Corporation, Intel, Microsoft, Oracle, SAP, and many more.

Another one of the KETs is *AI*, which is already affecting transportation significantly and autonomous driving capabilities. Advances in *deep neural networks* are one of the main drivers behind the impressive progress achieved in autonomous vehicles over the past decade, as well as with the advancement of *computer vision technology*. Competition of becoming a leader in the automotive-AI technology by Google, Baidu, Tesla, or Uber triggered automotive sector dominant actors, such as Ford or Honda, into investing in promising AI start-ups, forging alliances, or developing in-house capabilities (OECD, 2017a).

As a result, “2030 Automotive Revolution” suggests that the automotive sector is becoming more dependent on software technology. In that regard, AUTO-software companies and markets are emerging. There is also a huge shift to mobility-as-a-service in the global market both driven by technology and consumer demand. Which is evidently expected to force automakers to expand their competition landscape, along with new entrants. Mobility providers (such as Uber), tech giants (such as Apple, Google), and specialty OEMs (such as Tesla) increase the complexity of SIS. Traditional automotive sector dominant actors, which are also forced to improve fuel efficiency, reduce emissions, are shifting market positions in the new emerging AUTO-ICT sector via new forms of collaboration (McKinsey & Company, 2016). As can be observed while technology advances, cross-sectoral collaboration among the automotive sector as well as other sectors is significantly increasing due to the complexity of technologies and transformation of dynamics of the SIS, including demand and market, based on convergence.

From the perspective of **OECD Digital Economy Outlook 2017** (OECD, 2017a), the digital transformation and digital economy is firmly sets root on the global agenda. While it is emphasized that stimulating digital innovation across the economy is essential, there are many opportunities to improve networks and services through convergence of different communication technologies. There is also higher importance put on some KETs, such as *IoT*. Further results emphasize that the development of 5G is transforming the market and sectors even more as more infrastructures are deployed of *IoT devices and M2M* keeps growing. An essential example is given from *autonomous vehicles*, which also trigger the development of *big data technologies*.

In addition, according to **OECD’s Next Production Revolution Project** (OECD, 2017b), it is stated that two major trends make digital technologies transformational for production; one of them is resulting in market convergence as the combination of digital technologies, enabling new types of applications. KETs that are enabling the digital transformation of cross-sectoral production cause new market formations initiating by convergence. For instance, *additive manufacturing* (i.e. *3D printing*), *autonomous machines and systems* (which applies to *autonomous vehicles*), and

human-machine integration, are the applications through which the main productivity effects in a cross-sectoral perspective are likely to unfold. In combination, these KETs are leading the development of fully automated production processes, from design to delivery, as well as fully autonomous vehicles.

Furthermore, “**The Future of the Automotive Value Chain, 2025 and beyond**” report (Deloitte, 2017) highlights drivers of the transformation of the automotive value chain for the next decade in five pillars, which are technology, economics, environment, politics, and society. For the technology pillar, the most prominent KETs are stated as autonomous driving and connected cars, AI, telecommunication grid, energy storage, cybersecurity, vehicle capability, lightweight technology, 3D printing, human-machine interaction (cyber-physicals). Moreover, significant drivers for the value chain transformation of OEMs towards 2025 and beyond are also stated, for instance, e-mobility (demand-driven by either customers or regulators), autonomous driving (market-driven technology and major R&D focus), sharing economy (entirely different market, data and mobility management, further ways of monetizing data), different business models (financing and leasing offers, white label manufacturing such as contract manufacturing of different parts, customization, and personalization), and digital business models (demand-driven by customer, and fast pace of technology especially regarding infotainment and mobility services), Industry 4.0 (*manufacturing 4.0, smart factories*), workforce transition (especially regarding AUTO-ICT emerging markets and KETs). Key initiatives for the future car company in the AUTO-ICT global market by 2025 are determined as being a data and mobility manager (full capacity in *e-mobility, autonomous driving*, applicable business models for sharing economy, digital business models, and high-skilled workforce transition).

In order to understand the technology and convergence trends better in the automotive sector, technology roadmaps are also considered. One of the inclusive technology advancement roadmaps is prepared by the Center for Automotive Research Group (CAR Group, 2017). In the “**Roadmap for Automotive Technology Advancement**”, three key areas are covered. Which are (1) *intelligent mobility technology*, (2) *materials and manufacturing processes*, (3) *light duty vehicle propulsion*.

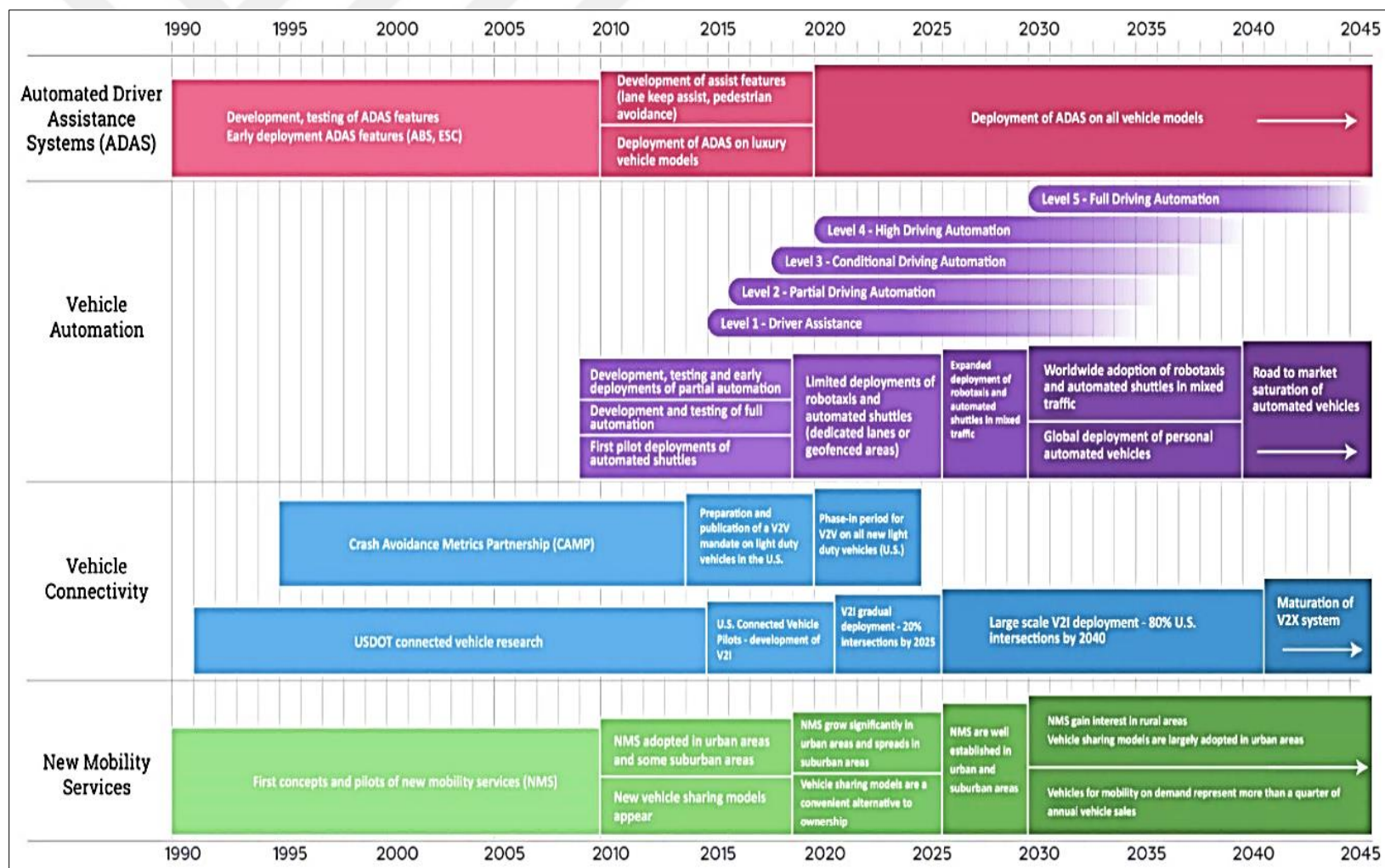


Figure 5.24. Roadmap for Automotive Technology Advancement: Intelligent Mobility (CAR Group, 2017)

Figure 5.24, above, presents the roadmap for intelligent mobility technologies from 1990 to the 2040s. Regarding intelligent mobility technology, over the past ten years, the sector has demonstrated increased advancement in four KETs: *Advanced Driver Assistance Systems (ADAS)*, *vehicle automation*, *vehicle connectivity*, and *new mobility services*. Levels of autonomous vehicles are also presented in the figure. It is anticipated that fully autonomous vehicles (Level 5) are introduced into the market by roughly 2030; about ten years after Level 4 vehicles first become available.

Regarding materials and manufacturing, the market share is expected to differ among materials but light vehicles and their complex materials are dominating the global market, which presents a significant challenge for the automotive sector. For the light duty vehicle propulsion, investment in different technologies battery electric vehicles (BEV), hybrid-electric vehicles (HEV), plug-in hybrid vehicles (PHEV), and fuel cell vehicles (FCV) is expected. For this key area, consumer demand is estimated to become the main driver, besides regulations. However, it should be also be noted that relative cost competitiveness can be another influential factor, for example with *additive manufacturing/3D Printing*, *Industry 4.0*, and *new mobility business models*.

Accordingly, **2018-2019 OECD Project on Digital and Open Innovation** (OECD, 2019) reviews how digital transformation is changing business models and consequently innovation activities across a range of priority sectors, which are agri-food, automotive, and retail, with a focus on impacts on different actors (for example, start-ups, SMEs, large companies). Regarding AUTO-ICT cross-sectoral perspective, the project results suggest that rapid digital technology developments are completely shaping the automotive sector. Prominent KETs are vehicle innovations (for example, *car connectivity*, *autonomous driving*, *connected vehicles*, including advances in *robotics*, *AI*, *ML*), innovations in production (*implications of Industry 4.0 applications such as smart factories*, *cloud*, and *high-performance computing*), and new business models (for example, platform-based on-demand mobility services, such as Zipcar, Uber, Lyft; or after-sales services like predictive maintenance).

Nevertheless, all of these innovations bring data evolution to the automotive sector as well. Digital transformation is affecting the entire automotive sector as companies change their dynamics of engaging in innovation, and their capacities. This transformation of dynamics brings opportunities as well as challenges for different actors in SIS and NIS. Especially for changes in IS, it is emphasized that innovation cycles are changing, companies are requiring new skills and organizational capacities, new patterns of innovation collaborations are developing beyond company boundaries, furthermore emerging global competition and new market entrants are very effective. For example, the automotive sector, which is a manufacturing dominant sector, is being merged with service sectors that involve more ICT sector related knowledge, technology, and market-bases.

On the other hand, for the digital transformation of end-products automotive sector is having a mix of digital and physical components in their final products (*cyber-physical systems*). For instance, vehicles increasingly integrate digital features, such as advanced infotainment systems and other functionalities enabled by connectivity and data analytics, and these are becoming key considerations in consumers' purchasing decisions, which play a crucial role in the formation of market and market convergence.

Last but not least, Society of Motor Manufacturers and Traders (SMMT) and Frost & Sullivan report for **“Connected and Autonomous Vehicles: Winning the Global Race to Market”** (SMMT, 2019) analyses international markets of automotive dominant countries in the CAVs market, by presenting a CAV deployment index having dimensions as enabling structure, enabling regulations, and market attractiveness. Examined countries are UK, USA, Germany, South Korea, Netherlands, Japan, France, and China. According to the report, USA, Japan, and South Korea are stated as overall leaders for the “enabling structure” dimension, such as 4G coverage. While for the same dimension, France is the leader for “4G speed”, and UK is the leader for “the share of autonomous vehicles per miles”. In addition, UK is stated as the overall leader for “enabling regulations” (such as defined insurance liability for autonomous vehicles), and market attractiveness (such as demand

responsive transport) for the emerging CAVs global market. While Germany is stated as a leader for road traffic laws where Level 3 autonomous vehicles are approved in public roads (levels can be seen in Figure 5.24), USA is stated as a leader for general laws for autonomous vehicle deployment. Moreover, for the market attractiveness dimension, Germany is stated as the leader for ADAS, USA for connected vehicles. The report also presents an interesting view regarding the global dominant actors. While global OEMs such as Nissan and Volvo have established a roadmap for CAVs development, the UK still depends on national dominant technology actors to develop CAVs for the domestic market. The report also presents a technology roadmap for CAVs through 2035. £176.5 billion investment is forecasted by OEMs worldwide between 2018 and 2030, based on global OEM launch for the various levels of autonomous vehicles. It is emphasized that this amount of investment of a completely unforeseen level is going to drive the need for new business models and revenue streams for the market, and AUTO-ICT market convergence while transforming the market dynamics and chartering new growth paradigms.

From now on, trends for determined dominant actors for automotive and ICT sectors will be examined separately for countries and companies.

5.1.3.4. Cross-Sectoral Matching Analysis Based On Trends of Determined Countries

In this section research and details for cross-sectoral matching analysis based on trends of determined countries and international organizations. Examined and presented countries are USA, China, Germany, Japan, UK, South Korea, Canada, France, Singapore, and Taiwan. With this part of the analysis, it is aimed to focus on the upper structure of the market convergence, that how national innovation systems (also regional) are focusing on cross-sectoral approaches and transforming. The summary of this section can be found in Table 5.1 above.

United States of America (USA) is investigated first. Primarily, **The DARPA Grand Challenge: Autonomous Robotic Ground Vehicles (2004)** is put in focus (DARPA, 2004) because this DARPA challenge is particularly important for AUTO-ICT cross-

sectoral approaches. It is one of the first major attempts to use an award-based competition to attract and encourage novel performers and the development of breakthrough innovations with a cross-sectoral collaboration and focus. Although the longer-term aim was to accelerate the development of the technological foundations for *autonomous vehicles and self-driving ground vehicles* in defense, this challenge led to new technologies for other platforms (air, and watercraft, etc.) and sectors as well (directly to aerospace, automotive; indirectly energy, manufacturing), and invigorated the award-based challenges for promoting breakthrough innovation. Moreover, recent R&D and innovation strategy documents are explored. For example, **Strategy for American Innovation** (The US White House, 2015) is the main R&D strategy document of the country. It has three core components and one of them is investing in *advanced vehicles*. Including breakthrough developments *in sensing, computing, data science, vehicle-to-vehicle communication, and cutting-edge autonomous technology safety features into commercial deployment, precision decision-making of machine intelligence, full autonomy-self driving-vehicles*. There are a couple of recent strategy documents as well. One of them is **R&D Priorities for American Leadership in Wireless Communications** (The US White House, 2019a) that emphasizes the priorities and requirements for future industries, which are affected by the adoption of convergence of newer broadband technologies, such as 5G. Therefore, US investment focus is put on the benefits of the advanced technologies that 5G will support as well, including *autonomous vehicles*. Additionally, with **Artificial Intelligence (AI) for the American People** (The US White House, 2019b) **American Artificial Intelligence (AI) Initiative** is concerted. It is emphasized that transportation and automotive sectors are prior sectors to be supported with the AI strategy and initiative, especially *autonomous systems (such as drones, and self-driving vehicles)*, which offer tremendous benefits to the economy and society.

In the case of **China**, the most recent R&D and innovation strategy documents are researched. The primary R&D and innovation strategy for China is the **13th Five-Year Plan (2016-2020)**, which is dedicated to support national prioritized areas including the development of next-generation information technology and *new-energy vehicles* along with related KETs. These include *advanced semi-conductivity, robotics, additive*

manufacturing, intelligent systems, smart transportation, systems for high-efficiency energy storage and distributed energy, smart materials, efficient energy conservation, environmental protection. Additionally, the Plan promotes internet-based transportation infrastructure and digitalization as a part of “Intelligent Transportation” priority. The Plan also emphasizes accelerating the development of the *internet of vehicles/vessels* as improving *vehicle automation*, and the increasing use of smart operations including warning systems.

Moreover, China introduced and implements policies, such as **Made in China 2025 (MIC2025, 2015)** and **Internet Plus Action Plan (2016)** that includes national initiatives and that prioritize smart transportation, new-generation ICT in the manufacturing sector (for automotive as well), the development of *intelligent vehicles (and EHV)s* (Yuming et al., 2017). Accordingly, Internet Plus Action Plan also proposes to accelerate the connection of freight vehicles to the internet and promote intelligent technology applications, such as the internet of vessels and connected vehicles, while also aiming to improve the transportation system. Additionally, **“Implementation Plan to Promote Smart Transportation by Carrying Forward Internet Plus Convenient Transportation” (2016)** and **“13th Five-Year Plan for Modern Comprehensive Transportation System” (2017)** emphasize to accelerate the development of the *internet of vessels, connected vehicles, vehicle networking, and automatic driving technologies, green and smart transportation systems*. As well as, building a national wireless technology verification platform for connected vehicles. Furthermore, **“Medium- and Long-term Development Plan for Automobile Industry” (2017)** directly focuses on the next-generation ICT-based automotive sector in China and promotes new energy vehicles and intelligent connected vehicles. China also set up a special committee for cross-sectoral coordination for the related sectors aiming to accelerate the development of *connected vehicles, smart transportation, and self-driving*. Other prominent related KETs can be noted as advancing the deployment and application of *LTE-V2X*, and promoting the *integration of 5G with the connected vehicles*; as well as strengthening *information and network security*.

For **Germany**, the main R&D and innovation, as well as cross-sectoral strategy documents and initiatives are investigated. Germany is one of the world's leading automakers. The automotive sector is also the basis of Germany's economy. Considering global and national trends and competitive environment Germany is putting much importance on AUTO-ICT cross-sectoral developments. One of the main R&D and innovation strategy documents for Germany is **The New High-Tech Strategy 2020**, which sets six priority tasks that digital economy & society and *intelligent mobility* are just two of them. These two tasks together emphasize the importance of addressing the challenges inherent in digital technologies and intelligent mobility (Industry 4.0, intelligent services, intelligent data, cloud computing, digital network, digital science, digital education, and digital living environments, *intelligent transportation infrastructure*, innovative roaming and networking, *electro-mobility*, *advanced vehicle technology*, aviation, maritime technology, *cyber-physical systems*). Recently released **The New High-Tech Strategy 2025**, also puts focus on mobility as a main theme, which is changing fundamentally by the disruptive effect of digitalization and new technologies, also through the consequences of climate change. Alternative, pollution-free powertrains, and electromobility remain the focus of research, including *autonomous, networked driving or alternative drives, as well as big data and telecommunication technologies*, as well as promoting *EVs and charging infrastructure*. Related new research and innovation policy initiatives for the term of 2018–2021 include “Action Plan Automated and Connected Driving”, “Strategy Paper on Battery Research and Battery Cell Production” and “The Modernity Fund (mFUND) Research Initiative” that promotes data-based applications for mobility 4.0.

Germany also introduced and implemented several cross-sectoral strategies and national initiatives that regard international cooperation as a priority as well. One of them is **Germany International Automobile-ICT Cross-Sectoral Innovation Challenge** (CATAIallience, 2010) that is launched by The German Automobile Excellence Network (NoAE), in cooperation with the German Ministry of Economy and Technology, and at the international level in collaboration with Canadian Advanced Technology Collaboration (CATA) and the Networked Vehicle Association (NVA). This initiative aimed to support automotive and ICT sector companies in

developing cutting-edge technologies for cross-sectoral leadership. The main research areas included the development of the *vehicle as a living environment*, *vehicle and communication technologies*, *ICT-based eco-innovation technologies*, *ICT-based flexible production technologies regarding the automotive sector*. Another cross-sectoral initiative includes **AutoMobil Production Collaboration** by Fraunhofer Institute for Applied Research, which is one of the leading research institutes in Germany and the world (Fraunhofer, 2014). AUTO-ICT cross-sectoral collaboration initiative was launched by eighteen research institutes under Fraunhofer.⁹ In this collaboration, multi-, cross- and interdisciplinary research is supported in order to produce automobiles of the future in addition to automobile production processes, and private sector R&D input is provided.

There are two main areas of R&D cooperation with the private sector, (1) ICT-based technology and system production for the automotive sector and (2) techniques in sub-technology areas (*electro-mobility*) such as *alternative energy generation*, *energy storage*, *energy transfer for electric vehicles*. Under the collaboration structure, three main research areas and sub-research areas are identified which are:

(1) Research Projects of Car Body and Transmission Bodies:

- Process control systems (sensor technology, realization elements)
- ICT-based process planning, design, production technologies and tools

(2) Interior Structure Research Area:

- Seats and interior trim (lightweight construction materials, personalization, security, cleaning technologies)
- ICT-based driver panel (appearance, acoustics, comfort, modules, operation, control technology)

⁹ The institutes that involve in the collaboration are: Industrial Engineering, Chemical Technology, Production Technology and Advanced Materials, Factory Operation and Automation, Optronics, System Technologies and Visual Processing, Ceramic Technologies and Systems, Material Flow and Logistics, Production Engineering and Automation, Production Systems and Design Technology, Production Engineering, Surface Engineering and Thin Film, Industrial Mathematics, Materials Mechanics, Materials and Infrared Technologies, Machine Tools and Mold Technology, Non Destructive Testing Technologies, Structural Continuity and System Reliability, Environment, Security and Energy Technologies.

(3) Vehicle Mounting Research Area:

- Human-vehicle, vehicle-vehicle interface systems
- Advanced kinematics based robot systems
- Intelligent process tools
- Energy efficiency-oriented installation technologies
- ICT-based assembly and logistics technologies (sensors, RFID)

Finally yet importantly, **Germany's China Strategy 2015-2020** (Strategic Framework for Cooperation with China in Research, Science and Education) emphasizes one of the prioritized areas as *electric mobility and smart transportation*. It brings another focus on cross-sectoral international collaboration aiming to accelerate development in AUTO-ICT sector, by merging country capacities and markets.

The main R&D and innovation strategy for **Japan** is the **5th Science and Technology Basic Plan - Society 5.0 Strategy 2016** (Japan Industry News, 2016) that covers many aspects. The main focus, however, is the development of the society towards a *Super Smart Society, the Society 5.0*. The underlying idea is the combination of cyberspace – the information – with the physical space – the real world, which is *CPs* that is expected to bring a major shift in society. In regard to AUTO-ICT cross-sectoral perspective, the prominent KETs are *self-driving vehicles, trucks and drones, and their integration with robotics, AI and big data*. Unlike German's Industry 4.0 Strategy, it is not just about the digital transformation of manufacturing, and related sectors, but digital transformation across all levels. Moreover, unlike USA, which has long allowed industry to take the lead on projects such as autonomous driving and drone deliveries, Japan's central government is in a leading role. Within mobility two objectives are supported, which are as following; (1) promoting the use of *autonomous driving* taxis and buses for public transportation to make rural transportation more readily available, and (2) improving distribution and logistics efficiency by introducing innovations such as a single driver cargo truck in a convoy using *unmanned-following vehicle system* and *drones*.

On the other hand, one of the most prominent cross-sectoral national initiatives in Japan is, **Japan Automotive Software Platform and Architecture (JASPAR)**, which is established to pursue increasing development efficiency and ensuring reliability by standardization and common use of electronic control system and in-vehicle network, which are advancing and complexing (JASPAR, 2018). JASPAR is targeting mainly, (1) improving developments in productivity and significantly contribute to the advancement of the technology through standardization, and (2) establishing the fair basis for the competition of the automotive sector.

Figure 5.25 shows the JASPAR Members List as of September 2017, which also presents the cross-sectoral structure of the platform. With board members being HONDA R&D, Nissan and Toyota on the OEM side; DENSO on the Tier1 side. Additionally, some of the regular members being ISUZU, Mazda, SUBARU, SUZUKI on the OEM side; Bosch, Panasonic, Mitsubishi Electric, YAZAKI being on the Tier1 side; and IBM Japan, NEC, Toshiba Information Systems on the Software side and Infineon, TDK, Toshiba being on the semiconductors/electronics side. This structure and members can be recognized from the analysis results of Section 5.1.1 and Section 5.1.2. Last but not least, some of the KETs that are focused on AUTO-ICT cross-sectoral convergence can be suggested even by analyzing these members in detail. For instance, associate members include Argus Cyber Security (*information/cybersecurity*), Digital Contents (*digital media*), and Ubiquitous (*AI*) on the Software side. Another suggestion can be the international cross-sectoral collaboration regarding the members of JASPAR. For instance, most collaboration is with USA based companies.

OEM	Tier1		Soft/Tool		Semicon/ Electronics	Others
12	42		73		25	19B
Board member						
HONDA R&D Nissan TOYOTA	DENSO					Toyota Tsusho
Regular member						
ISUZU Mazda SUBARU SUZUKI	ADVICS AISIN AW AISIN SEIKI Akebono Brake Alpine ALPS Autoliv Autoliv Nissin Brake Bosch Calsonic Kansei Clarion Continental Automotive FUJITSU TEN Furukawa Electric Hitachi AMS JATCO JTEKT	Keihin Mitsubishi Electric Nidec Elesys NIPPON SEIKI NSK Panasonic PIONEER Ricoh SHOWA Sumitomo Electric TOKAI RIKI Toyota Gosei TOYOTA INDUSTRIES YAZAKI	ADC APRESIA APTJ ATS AUBASS Cadence CATS Change Vision eSOL ETAS FFRI FTL FUJI SOFT FUJITSU FUJITSU BSC Hitachi ICS IBM Japan	KPIT Mentor Graphics micware NEC Nihon Synopsys OMRON OTSL SCSK STABILITY Sunny Giken Toshiba Information Systems TOYO Trend Micro Vector Japan WITZ	Harman International HRS Infineon MegaChips Microchip MJKK Murata NXP Semiconductors Renesas TDK TOSHIBA Tyco Electronics	DNP DTRS KDDI SECOM TOPPAN TOYOTA CRDL
Associate member						
DAIHATSU Hino HYUNDAI Mitsubishi Motor UD Trucks	Delphi Automotive Systems Fujikura KYB Magna International MITSUBA NGK SPARK PLUG Toyodenso TRANSTRON Valeo Japan Yamaha Motor	A&D A&W Technology ACCEL JAPAN AIC AISIN COMCRUISE ANRITSU Argus Cyber Security AXE AZAPA BITS Brisson Canon ITS Digital Contents DIT dSPACE Eager	Eiwa Elektrobit GAIO HI CORP Hitachi High-Tech Ixia LAC Mamezou MITO SOFT NEC Solution Innovators Netagent NTT DATA MSE NTT DATA SBC PCI Solutions Systema Takasaki Kyodo Tata Consultancy	TOKYO ELECTRON DEVICE ARM TTTech Ubiquitous USE Wind River Xilinx Yokogawa	ADI ARM Cypress Innovates HI-LEX Hitachi ULSI Hosiden NTN ROHM Sanden Automotive Components SanDisk Shindengen Thine YOKOWO	Allion Japan Biz3 HAGIWARA Kyoei Sangyo MACNICA NTT DOCOMO OEC RENESES EASTON Ryoden Ryosan SANSHIN Shinko Shoji

Figure 5.25. JASPAR Members List as of Sep 2017 (JASPAR, 2019)

In the case of **United Kingdom (UK)**, the main R&D and innovation strategy comes forward as the **UK Industrial Strategy (2018)** which puts great importance on AI, the green economy, future transport systems and supporting aging population, and their integration in the cross-sectoral convergence perspective. Moreover, UK Industrial Strategy proposes and implements public-private sector initiatives for priority sectors of the country, one of them being the automotive sector with the “**Industrial Strategy Automotive Sector Deal**”. As one of the successful automakers being third in Europe among major automotive producing nations puts great importance on the transition to ultra-low and zero-emission vehicles by continuing to build the agile, innovative and cost-competitive supply chain needed to secure international investment. Some of the prominent KETs are *AI for the automotive sector, low-carbon automotive technologies including EHV and plug-in vehicles, connected and autonomous vehicle (CAV) technologies; digital infrastructure for the automotive sector; research, innovation and scaling up of battery technologies, new charging technologies including on-street and wireless projects; vehicle-to-grid, etc.* The UK Industrial Strategy also continues to support **The 8 Great Technologies of UK (2012)** that are selected after several analyses regarding UK scientific and business capabilities. One of the eight great

technologies is *robotics and autonomous systems (including autonomous vehicles, self-driving technology)* being developed for improving manufacturing, medicine, and transportation. In this regard, the UK seeks a £13 billion global market for robotics and autonomous systems by 2025. On the other hand, it is emphasized that advances of ICTs is transforming the automotive sector rapidly, and the market is evolving rapidly into a CAV sector (including *ultra-low emission vehicles (ULEVs) and intelligent transport systems*). While the digital transformation of manufacturing throughout the automotive supply chain, critical infrastructures are also emphasized and one of the KETs comes forward as *cybersecurity for CAVs*. In this regard, Figure 5.26 shows the **UK Automotive Sector Priorities for 2017-2022**, which sets a technology roadmap in the AUTO-ICT cross-sectoral perspective in accordance with the UK Industrial Strategy (SMMT, 2017).

In addition, **The UK Catapult Centers Network**, which is also a national initiative supported under the UK Industrial Strategy and overseen by Innovate UK, underlines the importance of cross-sectoral convergence including enabling new levels of physical, digital, and social connectedness. The Catapults are a network of technology and innovation centers designed to promote productivity and economic growth. There are nine Catapults (main offices) in the network per sub-technology area with a national presence covering over thirty locations (regional offices), including Connected Places Catapult (CPC, merging of Future Cities and Transport Systems Catapults, as of 2019) and Digital Catapult (DC). They are highly integrated with other related Catapults, such as Compound Semiconductor Applications, Energy Systems and High Value Manufacturing in the AUTO-ICT cross-sectoral approaches as well.

In addition, 5G test-bed in Bristol, which is a part of DC, is used for self-driving vehicle tests. In this regard, the **Centre for Connected and Autonomous Vehicles (C-CAV)** is established in 2015 (SMMT, 2017), and £17 million of funding was awarded to eight collaborative R&D projects in 2016. Targeted development in key areas includes real-world testing of *self-driving vehicles, design aspects for disabled users, integrating human behavior into CAV programming*. There is also an initiative called; **The Intelligent Mobility (IM) Accelerator** (CPC, 2020a, 2020b), which is a

partnership between CPC and Wayra UK, a start-up accelerator that is part of Telefónica Open Future. The initiative particularly focuses on *intelligent mobility*, including areas such as CAVs, connected infrastructure, transport data, and AI.

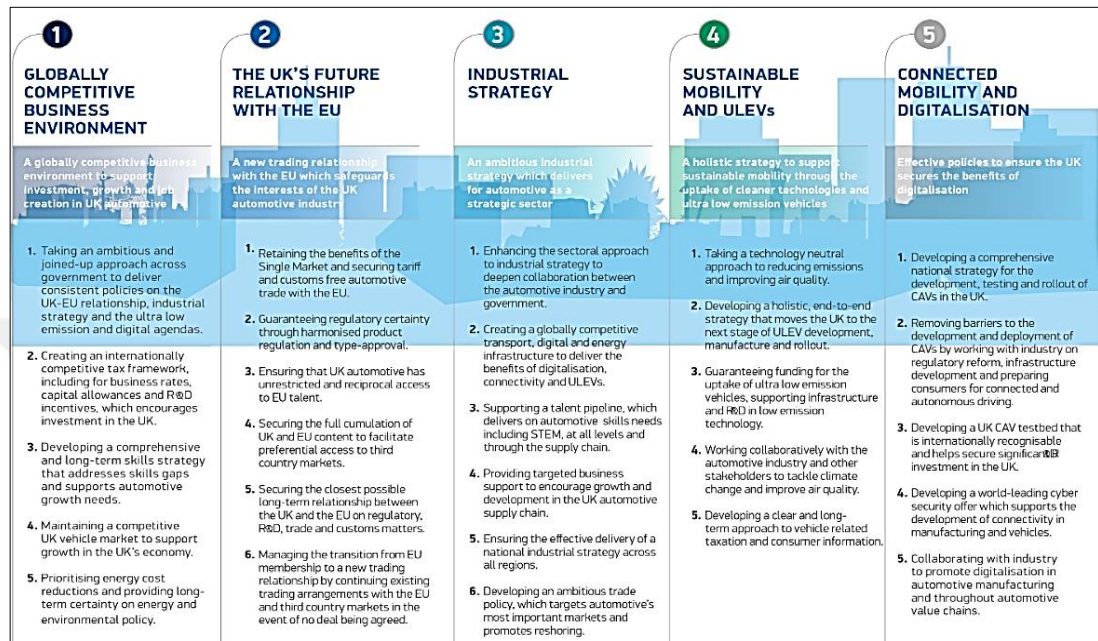


Figure 5.26. UK Automotive Sector Priorities 2017-2022 (SMMT, 2017)

For, **South Korea**, one of the recent R&D and innovation strategies come forward as **Creative Economy Strategy and Industry Initiatives (2013)**. Creative Economy Strategy encompasses four major pillars, nurturing creative talent, reinvigorating platforms for a creative economy, recreating venture/start-up ecosystem, and creating new sectors with S&T and ICT. Concerning the “Reinvigorating Platforms for Creative Economy” pillar, **Centers for Creative Economy and Innovation (CCEIs)** as an initiative of Creative Economy Strategy are established across seventeen cities and provinces in South Korea. CCEIs aim to provide better access and engage the private sector, very similar to the UK Catapult Network mentioned above. To boost the performance of CCEIs, each of them is matched with a leading company (relevant state-owned enterprises) in a given sector and sub-technology area that the city is specialized. There are fifteen prioritized sub-technology areas under **Creative Economy Industry Initiatives**, which CCEIs are also specializing, including

autonomous vehicles, unmanned aerial vehicles with high speed/vertical takeoff and landing. They are also closely integrated and in collaboration with other CCEIs, such as advanced material production systems, virtual work platforms, high-efficiency miniature (even smaller) production systems, as well as direct current power distribution systems, ICT-based energy supply management system. CCEIs provide venture capital, start-up incubation, one-stop-shop for finance, investment, legal, IPR, commercialization, and technical support. CCEIs are also working with the education and research infrastructures of the region. There are also international collaborations between CCEIs and global start-up centers, such as Silicon Valley, USA.

In the case of **Canada, Moving Forward in Science, Technology and Innovation (2014)** comes forward as the R&D and innovation strategy document for the country. There is a dedicated long-term support for the Canadian automotive sector by providing \$500 million to the **Automotive Innovation Fund** (Economic Action Plan 2014: The Road to Balance). KETs are one of the focuses of Canada's R&D and innovation strategy because their impact of creating entirely new areas with exciting possibilities for social and economic benefits is emphasized. With advice from the Science, Technology and Innovation Council, Canada has identified areas of particular focus within each of the five research priorities that are of strategic importance to Canada. ICTs (such as *communications networks and services, cybersecurity, advanced data management and analysis, M2M systems*), and *advanced manufacturing (such as lightweight materials and technologies, additive manufacturing)* are two of them. These research priorities aim to address the needs of Canada's key sectors, as automotive being one of them.

On the other hand, **Canada (ICT-Based) Automobile Excellence Center (Auto21, 2013)** is established to build a stronger automotive sector in Canada, but it is also an effort to establish an AUTO-based ICT sector and form an AUTO-ICT sector in Canada. It is funded by the Canadian Centers of Excellence Networking Secretariat (NCE) and has an annual research fund of 11 million dollars, which supports both public-private partnerships (PPPs) and cross-sectoral approaches. Under Auto21, there are forty-six universities, two hundred researchers, and one hundred and twenty PPPs.

R&D is carried out in multi-, cross- and interdisciplinary areas in line with private sector needs and R&D outputs are commercialized by PPPs. The main research areas for AUTO-ICT sector in the center are as follows; *health, safety and accident prevention, social problems and future car, materials and production technology, transmissions, fuels and emissions, design process, and intelligent systems and sensors.*

For **France**, firstly **France Europe 2020 (2013)** is examined. The France Europe 2020 agenda comprises a national research strategy, presenting objectives of addressing societal, scientific and technological issues and take up the challenges of competitiveness. The automotive sector is stated as France's largest sector. Some of the prioritized areas are given as *smart mobility and sustainable urban systems, development of the digital economy, in relation to the automotive sector* as well. Moreover, in France the **National Thematic Research Alliances** are specific national initiatives, aiming to improve the public research system and initiate strategic dialogue between the State and its operators. The Alliances are also able to state the scientific priorities for the research of the future and, in this manner, play a key part alongside The French National Centre for Scientific Research (CNRS) in building the strategic research agenda. CNRS held the world's first international race for molecule-cars, the **Nanocar Race**, in 2017. The vehicles, which consist of a few hundred atoms, are powered by minute electrical pulses during the thirty-six hours of the race, in which they were navigating a racecourse made of gold atoms, and measuring a maximum of a hundred nanometers in length. Beyond the competition, the overarching objective is to advance research in the area of *molecule-machines and cyber-physical systems when interacted with digital technologies, and as a consequence, embedding the results to prior sectors, such as automotive.*

In the case of, **Singapore**, which is dominant for ICT sector, mainly semiconductors, while there is no focus on ICT-based AUTO sector, there is an emerging focus on autonomous vehicles. As the R&D and innovation strategy of Singapore, **Research, Innovation and Enterprise Plan 2020 (RIE2020, 2015)** is considered. Four priority areas are stated as, Advanced Manufacturing and Engineering, Health and Biomedical

Sciences, Urban Solutions and Sustainability and Services, and Digital Economy. The RIE2020 Plan coupled with the **Smart Nation initiative** underlies the abovementioned priority areas drawing on digital technologies. For example, *digitally enhanced advanced manufacturing for sectors, such as automotive; or live digital simulations of fleets of autonomous vehicles to ensure system-level resiliency*. Singapore is also one of the hubs for international R&D collaborations, including with multi-national corporations. In this regard, **Agency for Science, Technology and Research (A*STAR, 2015)** is the most prominent research infrastructure of the country. There are more than twenty research institutes under the A*STAR that straddle the spectrum from fundamental to applied research, producing breakthrough science in various research areas, including electronics, infocomms (ICTs), robotics and automation, and security and transport. By aligning its research capacity with market demand, A*STAR has been able to leverage its semiconductor and ICTs R&D expertise to establish joint laboratories with industry partners as well as launch initiatives. **The Singapore Autonomous Vehicle Initiative** is one of them and it is a joint partnership between Land Transport Authority and A*STAR, that builds on image & video analytics capability of A*STAR, especially aiming to develop *self-driving buses* for mass transport services and establishing test-beds for autonomous vehicles.

Last but not least, A*STAR is collaborating with the Land Transport Authority to develop *a next-generation smart transportation system* as well. In collaboration with The Security & Transport Cluster, the focus is on *digital transformation of transport systems, enabling AI techniques to provide real-time traffic flow, and security*.

Lastly, **Taiwan**, another ICT-dominant country, is researched. **Technology and Innovation Driven Industrial Development Policy** by Ministry of Economic Affairs, R.O.C. is examined (2017). There are five main objectives under this strategy, one of them addressing development in the high-tech industry, namely “The “Two-Trillion and Twin-Star Industries” especially semiconductor and display sectors as twin-stars. Besides, there are several sectoral specific strategies, such as the strategy of “mobile services, mobile life, and mobile learning”. Which aims to expand the boundaries of

the broadband and wireless communication technologies sector, including *smart mobility*. Moreover, one of the objectives of the Strategy is “Promoting Taiwan as a significant R&D center based on its high-tech advantages”. With advantages in high-tech industry, Taiwan is introducing overseas R&D talent, technology, resources and systems, expecting to create a better niche. In this regard, one of the international initiatives comes forward as **Taiwan - Germany Automotive - ICT Cross-Sectoral Collaboration Platform (ITRI, 2013)**. The **Taiwan Industrial Technology Research Institute (ITRI)** established a cross-sectoral platform in 2012 in collaboration with German NoAE to provide high-tech ICT products to the European automotive sector and to open up to the global automotive sector. Within the platform, main research areas have been set up for the cooperation between Taiwan and Germany. These main research topics were as follows; *EHVs, telematics, new generation intelligent vehicles, innovative vehicle applications, and mobile security for in-vehicle communication*.

In this section, cross-sectoral matching analysis based on trends of dominant countries for automotive and ICT sectors by researching their national RDI strategies, specific landmark projects, national and/or international initiatives, and support mechanisms, etc. is presented. By researching dominant countries, the upper structure of market convergence is aimed to be examined, as well as its effects on the transformation of the dynamics of NIS. In this regard, reports by international organizations are also examined. For the examined countries and international organizations reports, AUTO-ICT cross-sectoral convergence is observed, especially regarding national/international markets. Moreover, KETs for AUTO-ICT sector is becoming very disruptive (such as CAVs), as well as creating and transforming knowledge, technology-bases, but also, market-bases of the NIS by introducing new actors, new institutions, new demands, new mission-oriented policies, new standardization requirements, new demand for high-skilled and interdisciplinary labor, new national/international collaborations, etc.

As a result, one of the interesting perspectives is; while automotive sector dominant countries such as USA, UK, Germany, and Japan show two-sided cross-sectoral

convergence, they are also collaborating with ICT sector dominant countries in order to become leaders of global markets for the emerging AUTO-ICT sector. On the other hand, ICT sector dominant countries, such as Taiwan, is focusing on ICT-based AUTO sector and collaborates with automotive dominant countries, such as Germany, in order to become a leader in AUTO-based ICT sector as well.

It should be emphasized that these international collaborations are also bringing the co-evolutionary aspects in focus for the markets. These conclusions are evaluated and presented in Section 5.1.3.2, including Table 5.1 that shows a summary of results.

5.1.3.5. Cross-Sectoral Matching Analysis Based On Trends of Determined Companies

While examining countries, as a second step, more focus is put on companies to understand market convergence better. In this section, cross-sectoral matching analysis based on trends of determined companies is presented in order to observe the inner structure of market convergence, that how sectoral innovation systems (SIS) are focusing on cross-sectoral approaches and transforming. Therefore, company R&D and innovation strategies, company press releases of recent projects, product foresights, cross-sectoral investments, and cross-sectoral collaborations are regarded for their cross-sectoral matching analysis for the determined dominant actors of automotive and ICT sectors. In addition, international market evaluations and outlooks are taken under consideration where needed.

Examined companies are Google LLC (Alphabet Inc., referred as Google), Microsoft Corporation (referred as Microsoft), Apple Inc. (referred as Apple), Siemens AG (referred as Siemens), General Motor Company (GM), Continental AG (referred as Continental), Ford Motor Company (referred as Ford), Volkswagen Group (VW), Toyota Motor Corporation (referred as Toyota), and Tesla Inc. (referred as Tesla). While mainly aforementioned ten dominant private sector actors are examined, other related dominant actors are also mentioned (such as BMW, Daimler, Chevrolet, Audi, Volvo, Nissan, TATA, and telecom companies, such as AT&T, Cubic Telecom, NTT;

moreover, digital platforms such as Uber, Lyft, etc.) depending on their relations with the examined companies.

There is a rapid pace of transformation of the automotive sector according to the advanced technologies such as *connectivity, autonomous driving, smart mobility, electric-hybrid vehicles (EHVs) and the user experience*, featuring new business models or sharing economy. In accordance with the global market trends, the findings of the previous sections demonstrated that one of the KETs that the global market is directing its investments is *autonomous vehicles* (including *connected cars* and *self-driving technology*). By 2026, the global autonomous vehicle market is expected to reach almost \$560 billion, with a growing CAGR rate of almost 40% between 2019-2026 (Autonomous Vehicle Market Outlook 2026, Allied Market Research, 2018). Google, Microsoft, and Apple stand out as the giants of the ICT sector, which are growing competition in the development of this in particular KET for the emerging AUTO-ICT sector. Moreover, they are competing with automotive sector giants, such as Continental, GM, and VW, in the rapidly developing global market. Interestingly, it is stated that while the automotive sector giants investing in this particular KET brings less return, even if they are developing their own products, cross-sectoral alliances are bringing more benefit for both the company and the development of the market. The fact that companies like GM and Toyota, which focus on in-house R&D on cross-sectoral dynamics, deviating from older strategies and focusing on cross-sectoral strategies are stated as a major market change, which also create market convergence (Muller, 2013).

In addition to autonomous vehicles, other prominent KETs that attract private sector investment and cross-sectoral strategies are *advanced vehicles* with alternative energy sources (EHV, PHEV, etc.) and *connected vehicles*. Accordingly, the global connected vehicles market is expected to grow 270% by 2022 with more than 125 million *connected passenger cars with embedded connectivity* to be shipped during 2018-2022 (Counterpoint Research, 2018). Relatively, it is estimated that the market for *in-vehicle connectivity* is expected to reach €120 billion by 2020. While the *cloud-based solutions* market for automotive is projected to grow to \$66.95 billion by 2022. This

creates a huge business opportunity, as well as market convergence, for both automotive and ICT sector dominant actors (Killian et al., 2017).

Moreover, from infotainment system to the shift of vehicle consoles, in-vehicle applications are becoming inevitable parts of the vehicles. The market size of the in-vehicle apps size is estimated to be valued around 60 million units by 2023. As of 2018, Apple's CarPlay and Android's Auto apps are anticipated to witness significant market growth owing to the increasing integration of these infotainment platforms in vehicles. It is expected that more than 24 million cars will be equipped with Apple CarPlay app by 2019. And, Android Auto is expected to be valued at around 31 million units by 2020 as well as Apple CarPlay is likely to be valued at 37 million units by 2020 (Global Market Insights, 2019).

In relation, *vehicle operating systems, autonomous systems (including 5G integration and IoT), M2M, V2V, M2X, V2X, V2H, and the support of AI and ML* are composing the direction of cross-sectoral investment, which are paving the way for CPs as well. While the connectivity and software infrastructure is developing, *data technologies* are also becoming prominent.

In that regard, *big data* and accordingly *cloud computing* investments are rapidly increasing, as well as *cybersecurity technologies*. Moreover, cross-sectoral strategies of intelligent mobility include other sectors, most crucially energy sector and related technologies, *advanced battery technologies, and telematics*. It should be noted that, *advanced manufacturing technologies*, such as *3D-printing*, and *advanced materials* for lightweight vehicles, are also becoming the focus of cross-sectoral investments and strategies.

First, **Google**¹⁰ is examined for its increasing investment in *autonomous vehicles (self-driving technology)*. The company is essentially known as the global leader for search engines (Statcounter Database, 2019) and a dominant actor in the ICT sector. Looking at the cross-sectoral acquisitions of the company, Google acquired ZipDash and Latent Logic as early as 2004. ZipDash tackles highway congestion by providing individuals with *real-time, accurate traffic information*. Latent Logic is a *deep learning technology for autonomous vehicles* and as recent as 2019 has become a part of Waymo LLC (Waymo) (Crunchbase, 2020a, 2020b). **Google's Strategy for Changing the Automotive Sector Forever: "Self-Driving Car Technology"** shows the huge interest and investment of the company in becoming a leader for the emerging AUTO-ICT sector, since the ICTs is playing a crucial role in the formation of the automotive sector. Essentially, Google *self-driving car* project began in 2009 and the company created a new and complex competitive landscape for the future of the automotive sector and global market, with accomplishing the challenge of driving more autonomous miles than had ever been driven before in collaboration with Toyota (Chavey, 2013; Waymo, 2019). Later on, in 2013, the company stated that self-driving technology is foreseen to change the automotive sector entirely and their strategic investment is directed to this KET particularly, where the automotive sector giants are also setting their feet.

With increasing investment, in 2016, **Waymo** is established as a spin-off of *self-driving technology* and an *autonomous vehicle* development company, a subsidiary of Google's parent company, Alphabet Inc. In 2017, Waymo collaborated with Fiat Chrysler Automobiles (FCA) and designed a fully integrated hardware suite (Waymo, 2019). When the social effects of technology are also considered, autonomous vehicles are expected to reach hundreds of billions of annual revenue, or even trillion dollars, from all sorts of entities while also arising the high profitable business opportunities.

¹⁰ Google LLC is an American multinational technology company that specializes in Internet-related services and products, which include online advertising technologies, search engine, cloud computing, software, and hardware. As of 2015, Alphabet Inc. is created through a corporate restructuring of Google and became the parent company of Google, and several former Google subsidiaries.

Accordingly, Google is now taking one of the leads in this particular cross-sectoral global market, along and in collaboration with automotive sector dominant actors (Mui, 2013). Google's investment in autonomous vehicle technology is stated to be effective for automotive sector dominant actors to realize the benefits of R&D collaborations with the ICT sector leaders.

Another cross-sectoral global market for AUTO-ICT is *vehicle (automobile) operating systems*. Google's cross-sectoral alliance "**The Open Automotive Alliance (OAA)**", founded in 2014, is one of the featured cross-sectoral strategies in this regard (Google OAA, 2014). Google is aiming for the dominant use of Android platform -which is Google's mobile operating system market leader- in the automotive sector. Therefore, OAA is established as a global partnership of Google with Audi, GM, Honda, Hyundai Motor, and NVIDIA. Since OAA is an open partnership, it is expanding its reach to global automakers, aftermarket, and technology dominant actors.¹¹ There is also cooperation with public institutions such as the National Road Traffic Safety Administration. More simply, OAA is targeting to create *connected vehicles*.

On the other hand, **Microsoft**¹², which is essentially known for dominating the operating systems global market, has a directed R&D and innovation strategy for the automotive sector for decades. For instance, Microsoft collaborated with **Ford** to create *connected vehicles* as early as 1995, with a project called "**Microsoft Automobile**", which is also a vehicle that is personalized and integrated with social network technology. Accordingly, two companies collaborated in 2013 again to foster the use of connected vehicles (Chavey, 2013). Ford also powered with Microsoft for

¹¹ Automaker partners include automotive giants such as Alfa Romeo, Bentley Motors, Buick, Cadillac, Chevrolet, Chrysler, Citroen, Dacia, Fiat, Ford, Jaguar, Kia, Lamborghini, Landrover, Mazda, Mercedes Benz, Mitsubishi Motors, Nissan Global, Opel, Peugeot, Renault, Renault Samsung Motors, Seat, Skoda-Auto, Subaru Global, Suzuki Global, Tata Motors, Toyota, VM, Volvo Cars. Aftermarket partners include Boss Audio Systems, JVC Kenwood, Mongoose Automotive Technologies, Nakamichi Car Audio, Panasonic, Pioneer Electronics, Sony, and technology partners include Bosch, Cloudcar, Continental, Denso, and LG.

¹² Microsoft Corporation is an American multinational technology company that develops, manufactures, licenses, supports, and sells computer software, consumer electronics, personal computers, and related services. Microsoft dominates about 90% of the PC operating system market in 2018, as it did in 2013 (Netmarketshare, 2014 and 2019).

the software technologies. For example, Microsoft created “**Microsoft Auto Software**”, which can interface with any MP3 player, Bluetooth device, or smartphone; and the software is integrated with **Ford SYNC**, a system for *in-vehicle communications and infotainment*, in 2008. The introduction of SYNC-like systems triggered other automakers to launch similar systems. For instance, **GM** has expanded its OnStar service and integrated SYNC-like features into its infotainment system and has even added smartphone apps so drivers can do things like unlocking and starting their cars remotely (Ford, 2011).

In addition to its collaboration with Ford in 2013 regarding the cross-sectoral convergence trend, Microsoft also established the “**Microsoft Automotive Sector Innovation Center**” in China in terms of global competitive leadership in the automotive sector, which is also an objective in “**Microsoft’s Automotive Sector Strategy, 2013**” (Qing, 2013). It is stated that the center's operations mainly cover four global trends for the emerging AUTO-ICT sector, which are; *mobile, social networking, cloud computing, and big data*. Recently, Microsoft is poised to offer the most customized, smart, and smooth driving experience, thanks to its innate strength in operating systems and the most cutting-edge innovations in *AI, voice recognition, multi-touch, and gesture recognition*. In 2017, Microsoft launched its “**Connected Vehicle Platform**” that includes all aforementioned KETs based on Microsoft’s cloud computing service platform, Microsoft Azure. KETs that are primarily focused regarding the AUTO-ICT sector are, *predictive maintenance, improved in-vehicle communication, advanced navigation, customer-based interaction, and self-driving technology*. Connected Vehicle Platform is composed of partners such as Ford, Volvo, Nissan, Harman, IAV, Toyota, Delphi, TATA, VW and Qoros. With this cross-sectoral strategy, Microsoft is targeting to become a leader for in-vehicle platforms for CAVs in the global market. On the other hand, Microsoft and VW collaborated for creating “**Volkswagen Automotive Cloud**”, using *cloud computing* capabilities and IoT Edge platform. From 2020 onwards, it is forecasted that more than five million new VW vehicles will be fully connected and part of the IoT based on the cloud (Microsoft, 2018).

Additionally, BMW, Grab¹³, Daimler, Cubic Telecom¹⁴, AKKA Technologies¹⁵ and ICONIQ Motors¹⁶, Cognata Ltd.¹⁷, Elektrobit¹⁸, Baidu¹⁹ collaborated with Microsoft to use its *cloud* and *AI* capabilities. It should be emphasized that these collaborations are all two-sided, in order to realize goals for transforming the global market and emerging AUTO-ICT sector, such as *fully autonomous vehicles*, by using respective technology advancements and global market capabilities. Microsoft, for instance, collaborated with **Apollo Open Platform Alliance**²⁰ (China) using its cloud computing capability (Azure) to bring the global market into the alliance. The company also works with Mercedes-Benz Brazil to improve customer service in its trucks division, using AI and ML capabilities, with Toyota to improve the after-sales services by leveraging telematics, IoT, and cloud computing, with Adobe to create a platform for automakers to get a 360-degree view of their customers to transform the customer experience.

As of 2018, with a renewed cross-sectoral strategy, Microsoft continues to dedicate its strategic investment and transform the emerging AUTO-ICT sector with its

¹³ The leading on-demand mobility services platform based in Southeast Asia.

¹⁴ A pioneer in SIM card-based technologies, regarding connected vehicle technologies, based in Ireland.

¹⁵ A global leader company for digital industrial technologies in various sectors including automotive sector, based in France.

¹⁶ Mainly EHV company, based in China.

¹⁷ Leader for simulator technologies regarding cloud-based autonomous vehicle, ADAS and on-demand GPU clusters, based in Israel.

¹⁸ Automotive Software Company, based in Germany.

¹⁹ Essentially known as Google of China, Baidu is one of the largest AI and internet companies globally, directing its investment to autonomous vehicles and self-driving technology as well.

²⁰ China based open, reliable and secure software platform for its partners to develop their own autonomous driving systems through on-vehicle and hardware platforms, launched in 2017. Apollo has almost 130 worldwide partners and their Chinese branches that include Adayo, Bosch, Ford Motor, BMW Group, Continental, Daimler, Delphi, Honda, Hyundai, Intel, etc. Beihang University, Beijing Institute of Technology, Tongji University, Tsinghua University are also parts of the platform.

technology development. The main KETs for cross-sectoral convergence are, *advanced connected and autonomous vehicles, smart mobility, telematics, creating connected marketing, sales and service experiences, transforming factories, supply chains and operations (smart factories, industrial automation)* in collaboration with automaker giants and global leaders in specific technologies.

Apple²¹, on the other hand, which is known as one of the leading smartphone manufacturer companies globally, having a market share of 18% (closely competing with Samsung) as of 2018 (Counterpoint Research, 2019), shows prominent cross-sectoral strategies as well. The company also competes in the mobile operating systems market with Android, which has over 30% market share whereas Apple iOS is 14% (Startcounter, 2019); therefore, Apple's plans for the emerging AUTO-ICT sector are very significant.

Looking at cross-sectoral strategies and investments for Apple, which is considered as one of the big four technology companies, alongside Amazon, Google, and Microsoft, focusing on *autonomous vehicles supported by AI, vehicle operating systems, and in-vehicle communication* can easily be observed. For instance, recent cross-sectoral acquisitions of Apple include VocalIQ in 2015 that provides a platform for *voice interfaces, voice enabled devices and apps for the automotive sector*; and Drive.ai in 2019, that creates *AI software for autonomous vehicles* (Crunchbase, 2020c). In its cross-sectoral R&D and innovation strategy Apple, primarily, directs its investments on “**Apple iOS in the Car**” targeting CAVs (Zach, 2013). Apple iOS having high compatibility with the vehicle components plays an important role for the company to target global leadership in this area, with dominating the particular global market 100%, by 2023. Currently, **Apple CarPlay**, which is an iOS-based platform for iPhones in the vehicle providing smartphone features to be used by built-in display while driving, is available for limited cars by several automaker leaders, such as Audi,

²¹ Apple Inc. is an American multinational technology company that designs, develops, and sells consumer electronics, computer software, and online services.

BMW, Ford, Honda, Hyundai, Nissan, Opel, TATA, Toyota, etc. and over five-hundred models. Also supported by aftermarket companies such as Pioneer, Sony, JVC Kenwood, Clarion, Alpine (Apple, iOS CarPlay, 2019). However, Apple also directed its cross-sectoral investment on developing *EHVs* starting in 2014, soon after, the company shifted its focus to *autonomous driving software* rather than a full-on vehicle, with “**Project Titan – Apple Autonomous Vehicle Project, 2018**” (iMore, 2019). Of course, cross-sectoral alliances with automakers are one of the crucial strategies for the particular project.

It should be noted that, several sources are suggesting that there is a continuous “Apple Car” vision (as the next landmark product) and development in the process that is expected to release as soon as 2023, where Apple-designed chips being manufactured by TSMC²². In 2017, Apple started testing its *self-driving vehicle software* embedded in Lexus vehicles.²³ In late 2017, new *LiDAR sensors* in the self-driving vehicle testing (which is aimed to be revolutionary for the future autonomous vehicle), and as of middle 2018, the company had seventy vehicles using its autonomous driving software. Finally yet importantly, Apple is also targeting to establish a self-driving shuttle service, namely “Palo Alto to Infinite Loop. (PAIL)” in Silicon Valley, while also partnering with VW to integrate self-driving software in Volkswagen T6 Transporter vans to serve as an employee shuttle (iMore, 2019).

Another ICT sector dominant actor, **Siemens**²⁴, focuses on *electrification, automation and digitalization*. Looking at the cross-sectoral investments of the company, Furnas Electric Co. is acquired by Siemens Energy and Automation, in 1996. A company that

²² Taiwan Semiconductor Manufacturing Company, Limited (TSMC) is a Taiwanese multinational semiconductor contract manufacturing and design company.

²³ Lexus is the luxury vehicle division of the Japanese automaker Toyota.

²⁴ Siemens AG is a German multinational conglomerate company (an engineering and electronics company) and the largest industrial manufacturing company in Europe with branch offices abroad, that specializes in the fields of industry, energy, transportation, and healthcare.

develops *electrical and motor control products*. On the other hand, in 2017, TASS International is acquired by Siemens that supports the global automotive sector in the creation of *safer and smarter vehicles* (Crunchbase, 2020d).

Siemens puts the *cyber-physical systems* at the basis of its R&D project “**Reliable Control and Automation Environment (RACE) – Software Car**” for the automotive sector (Siemens, 2012a, 2012b). Siemens states that the future of the automotive sector is directly affected by the orientation of the ICT sector and that the two sectors are converging in a disruptive way to form an entirely new automotive sector. RACE is a project to standardize ICTs in vehicles. The ICT architecture is also seen as central to future automotive technologies such as *autonomous driving, drive-by-wire, connectivity, Car2X communication, and human-machine interaction*. New infotainment, driving, and assistance functions are software-based rather than being implemented with a hardware controller so that vehicles are becoming upgraded and updated for their entire life cycles. The RACE Project is funded by BMWi (The Federal Ministry for Economic Affairs and Energy of Germany) research project with eight consortium partners, a three-year project with an amount of € 10 million. It was launched at the beginning of 2012 having Siemens as the lead partner, TRW²⁵ as an automotive supplier, AVL²⁶ as a service provider, as well as five leading research institutes of the country. The main KETs for the project are a new *software-based vehicle, sensor technologies, machine-to-machine, human-machine interaction, information security, embedded systems, and IoT*. In addition, outcomes of the RACE Project by 2018 show that transfer of middleware into non-automotive areas, such as factory automation and the energy sector (Jambit, 2018). More recently, Siemens also targeted its investments for *automation solutions for automotive manufacturing*

²⁵ TRW Automotive Holdings Corp. is an American global supplier of automotive systems, modules, and components to automotive original equipment manufacturers and related aftermarkets.

²⁶ AVL, or Anstalt für Verbrennungskraftmaschinen List, is an Austrian-based automotive consulting firm as well as an independent research institute.

processes incorporation with automotive sector dominant actors. Another fast-paced technology combining automotive and ICT sectors is **Siemens Digital Twins and e-Car** (Siemens, 2018). A digital twin is a virtual representation of a physical product or process, used to understand and predict the physical performance characteristics. While the demand for efficiency increase in vehicle design and production, with Siemens Digital Twins encompasses the entire value chain and exists in three variants for e-Car production. There are two main partners, (1) Hyundai Motor Corporation (South Korea) targeting 40% less physical vehicle testing with real-time simulation for HEVs, and (2) Uniti (Sweden) targeting the optimization of the production of all digital EV for cities.

On the other hand, to have an understanding of cross-sectoral approaches from the perspective of automotive sector dominant actors, first **General Motors (GM)**²⁷ is researched and examined. GM is one of the leaders in the world's largest and fastest-growing automotive global markets. GM's subsidiaries include OnStar, a global leader in *vehicle safety and security services*, and Maven, its *mobility* brand. GM targets to transform the automotive sector for the 21st century by focusing on KETs such as *self-driving technology, EHVs and other alternative fuel vehicles, sharing economy, lightweight vehicles, connected vehicles (V2V, V2I, V2X, C-V2X), 3D-printing* (GM, 2019). GM sets a vision for beyond 2030s, CAVs with all types of EVs and on-board charging stations, safe and an emissions-free as an ecosystem with a drastic transformation of entire mobility systems (GM, 2018). With Cruise Automation and Cadillac Super Cruise semi-autonomous systems available in the US and China, GM is already a global pioneer in *self-driving vehicle technologies*. Additionally, GM is working on hydrogen fuel cell EVs and cell-powered EVs with close collaboration with sector partners. In 2016, GM was one of the first automakers in China to show

²⁷ General Motors Company (GM), commonly referred to as General Motors, is an American multinational corporation that designs, manufactures, markets, and distributes vehicles and vehicle parts, and sells financial services. GM, its subsidiaries and joint venture entities sell vehicles under the Chevrolet, Buick, GMC, Cadillac, Holden, Baojun, Wuling and Jiefang brands.

V2X technology interoperability; moreover, GM recently took part in the world's first multi-industry demonstration of cellular-connected vehicle communications (C-V2X).

Furthermore, in line with the rise of sharing economy, such as Uber, Grab and Lyft, there is a decline for owned driver's licenses, especially by young people. In 2016, GM following this global market trend closely, invested in Lyft to develop an on-demand *network of self-driving vehicles*. GM's Maven, a personal mobility brand, is an investment in sharing economy as well for flexible ways to get on the road faster. Moreover, GM and Amazon recently announced a collaboration to bring an *in-vehicle Alexa system*, to connect and control smart home devices by voice while on the road (GM, 2018). On the other hand, GM is using new, advanced software design technology to introduce the next generation of *vehicle light weighting*. The technology is key to developing efficient and lighter alternative propulsion and zero-emission vehicles. Automakers like GM are pioneers in using *3D-printers* for vehicle production. In 2018, GM collaborated with software company Autodesk Inc. to manufacture new lightweight 3D-printed parts. By 2025, GM hopes to produce entire vehicle components at scale as the *3D-printing and advanced materials technology* improves, thus also visioning *cyber-physical systems*, like the use of shape-shifting transformable *4D printed materials*.

While the market differentiates from other determined companies for the case study, Continental becomes front as one of the major and dominant players from cross-sectoral perspectives as well. **Continental**²⁸, being one of the lead automotive engineering service providers (ESPs) in the market in competition with other ESPs such as Denso, Aisin, ZF, Delphi, Hitachi, the company has a vision for *intelligent mobility technologies, transporting materials, and automotive data technologies*. The

²⁸ Continental AG is a German multinational automotive manufacturing company specializing in brake systems, interior electronics, automotive safety, powertrain and chassis components, tachographs, tires and other parts for the automotive and transportation sectors.

company emphasizes that especially AUTO-based consumer electronics and software sectors are radically converging (Continental Mag., 2019). The company collaborated with NVIDIA and focuses on *self-driving vehicle systems*. They began open road trials of this KET in 2012. Moreover, Continental collaborated with BMW and Google for increasing research capacity particularly for developing *autonomous vehicles*, in 2013. Other than the aforementioned collaboration back in 2013, which is still continuing, Continental became a part of “**Autonomous Vehicle Computing Consortium**” in 2019 in order to develop and become one of the lead actors in autonomous driving technology. As of March 2020, 40+ corporations working on autonomous vehicles. Alongside with Continental, some of the partners of the consortium include Bosch, Toyota, GM, NVIDIA, and NXP (CB Insights, 2019).

For the purpose of looking at the emerging AUTO-ICT sector from the perspective of one of the world’s largest automakers, **Ford Motor (Ford)**²⁹ is examined separately. The company’s R&D and innovation strategy includes building *fully autonomous vehicles* by 2021. In addition, for the strategy of being the leader for *intelligent mobility systems*, Ford Smart Mobility LLC is founded in 2016 (Ford Company, 2019a). Ford also expanded its research in *data analytics*, *3D mapping*, *radar technology*, and *sensors*. Thus, the company invested in Velodyne, SAIPS, Nirenberg Neuroscience LLC and Civil Maps, which are specialized companies in the aforementioned KETs. On the other hand, Ford Smart Mobility LLC made cross-sectoral acquisitions as well since it was founded (Crunchbase, 2020e). These include *intelligent mobility systems* developers such as Journey Holding Corporation, TransLoc, Chariot and Spin. Moreover, as recent as 2018, Autonomic is acquired which serves as a *vehicle connectivity platform*. Finally yet importantly, in addition to the extensive testing of autonomous vehicles and intensive collaboration with outside partners, Ford is focusing on expanding its Silicon Valley presence by creating a dedicated hub,

²⁹ Ford Motor Company, commonly known as Ford, is an American multinational automaker, founded by Henry Ford and incorporated in 1903.

including expanding The Ford Research and Innovation Center (2015) for developing the abovementioned KETs in particular (Ford Company, 2019b).

On the other hand, **Volkswagen (VW)**³⁰, the largest automaker by worldwide sales, also directs its investment to *broadband technologies, advanced electronics, and new battery technologies, M2M, human-machine interaction technologies, intelligent systems, sensor technologies, big data technologies, cloud computing* to realize its vision for “**Fully Interactive and Smart Cars**” of the future (Volkswagen, 2013, 2018). To realize this vision, the company’s “**Transformation 2025+**” strategy emphasizes that AUTO-ICT cross-sectoral convergence is removing constraints for the automotive companies, such as time, cost, and the future automobile will evolve into a central hub in the IoT. Therefore, according to the same strategy the company is predicting to invest \$4 billion by 2025 just for developing *new digital businesses and products in the IoT*.

Moreover, recent cross-sectoral acquisitions of the company show that, as recent as 2018 VW acquired WirelessCar (based in USA) which is a provider of manufacturers of vehicles and commercial vehicles with customized *telematics services* to end-customers (Crunchbase, 2020g). In this regard, VW also invests in creating a “Volkswagen We” ecosystem and “**transform from automaker to mobility service provider**”, by creating; a cloud-based platform “One Digital Platform” and “Volkswagen Connect” to start adding over five million new vehicles each year as the part of IoT starting at 2020.

³⁰ Volkswagen Group is a German automaker founded in 1937 by the German Labour Front. It is the flagship marque of the Volkswagen Group, the largest automaker by worldwide sales in 2016 and 2017. Volkswagen Group represents over ten brands including, Volkswagen Passenger Cars, Audi, ŠKODA, Bentley, Bugatti, Lamborghini, Porsche, Ducati, Volkswagen Commercial Vehicles, and Scania.

Another global leader in the automotive sector, **Toyota Motor (Toyota)**³¹, strategizes shifting toward a "**smart mobility company**" with realizing the future mobility society via its ICT-based cross-sectoral strategy "**CASE**" and "**Smart Mobility Society**" (Toyota, 2013). In this regard, the company focuses on KETs as *c*onnected vehicles, *a*utonomous/self-driving, (*c*ar-/ride-) *s*haring, and *e*lectrification (*underlined letters are the capitals for CASE strategy*).

Additionally, other prominent KETs include *new generation telematics, connected systems (smart systems and smartphones), new generation network and mobile technologies, human-vehicle interaction, M2M, human-to-machine interaction technologies, embedded systems*. There are four dimensions to Toyota's "Smart Mobility Society" strategy, which are;

- (1) New Generation Telematics: Focuses on FV2 model with *human-machine (vehicle) interaction, cloud computing, data centers, big data technology*.
- (2) Intelligent Transportation Systems: Focuses on *autonomous driving, vehicle-to-pedestrian and V2V interactions*.
- (3) New Generation Public Transport Traffic System: Focuses on EVs, called "i-Road", integration of public transportation and mobile technologies.
- (4) Energy Management: Focuses on green technology-based eco-society, and energy efficiency, integration of *vehicle-to-building* (especially houses) mutual charger systems controlled by smartphones, creation of an ecosystem of producers-consumers, called as prosumers.

Moreover, in accordance with Toyota's "Smart Mobility Society" strategy, a recent collaboration with Nippon Telegraph and Telephone Corporation (NTT) seeks to establish technologies for *connected vehicles* (Toyota, 2017). Areas of collaboration

³¹ Toyota Motor Corporation is a Japanese multinational automotive manufacturer headquartered in Japan. One of the global leader automakers in the world by revenue as of December 2019.

include prominent KETs such as *IoT, big data, 5G mobile communication, edge computing, AI*.

Lastly, **Tesla**³², being one of the pioneer actors in EHV and clean energy sector, and involvement in R&D of software applications is examined. First and foremost, from the perspective of cross-sectoral convergence the company also refers to itself as a software company alongside being a leading automaker (Tesla Inc., 2018). In that regard, the company's strategies include KETs such as autonomous vehicles that are integrated with solar panels of houses, while also visioning to transform the entire value chain of the automotive sector. For instance, Tesla Model S, has full self-driving capability, 17" touchscreen, on-board software updates, and mobile service. Tesla specializes in *EV manufacturing, battery energy storage from home-to-grid scale*, and through its acquisition of SolarCity (acquired as of 2016 by a total price amount of \$2.6 billion), solar panel and solar roof tile manufacturing. Looking at the other investments of the company, six big acquisitions since 2015 (Crunchbase, 2020f) can be seen, which are;

- (1) DeepScale is a technology company that develops *perceptual systems for semi-autonomous and autonomous vehicles*, acquired as of 2019.
- (2) Maxwell Technologies is *a manufacturing and marketing energy storage and power delivery solutions for automotive*, acquired as of 2019.
- (3) Perbix is a maker of *highly automated manufacturing equipment*, acquired as of 2017.
- (4) Grohmann Engineering is a German engineering organization that specializes in *electronics, automotive, biotech, life science*, acquired as of 2016.

³² Tesla Inc, formerly Tesla Motors Inc. is essentially an American electric vehicle and clean energy company. Tesla's current products include electric cars, battery energy storage from home to grid scale, solar panels and solar roof tiles, as well as other related products and services.

- (5) Riviera Tool LLC is a manufacturer of stamping die systems used to form sheet metal parts (*automobile and truck parts such as body panels, doors, and bumper*), acquired as of 2015.

According to ARK and Forbes, Tesla resembles Apple in three key areas for the transformation of the automotive sector: a strategy of vertical integration, an imminent product inflection, and a business model transitioning from hardware to services (ARK, 2018; Marr, 2018). Especially regarding the strategy of vertical integration, Tesla emphasizes selling an ecosystem and not just a car, just as Apple's strategy of vertically integrating software, hardware, services, and retail. On the other hand, vertical integration strategy also transforms into horizontal integration when cross-sectoral approaches are concerned. For example, it is noted that iPod and iTunes combination of Apple created a dual revenue from both hardware and music, which is considered as vertical integration of its product line.

Accordingly, Tesla visions to create an entire ecosystem in addition to its vertical integration thus becoming a horizontally integrated company as well. For this purpose, Tesla also pursues an "Energy Management Strategy", similar to Toyota's "Smart Mobility Society" strategy and the company invests in the energy sector heavily, as abovementioned. Another competitive advantage for pioneering in the global market is also emphasized as in-house development of KETs, such as Apple's advantage of creating its multi-touch system, or Tesla developing its AI hardware and founding OpenAI.

In this regard, Figure 5.27 shows a vertical integration strategy and the respective "ecosystems" built up by Apple and Tesla in comparison, by services, software, hardware, production (ARK, 2018).

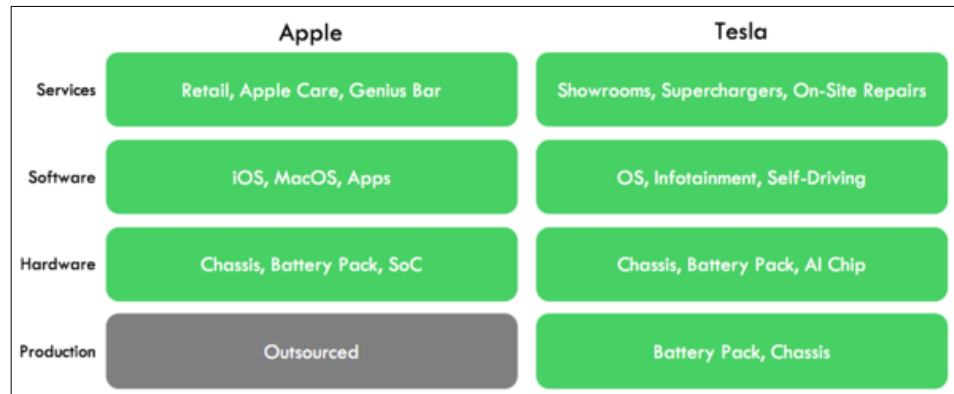


Figure 5.27. Comparison of Apple and Tesla for Vertical Integration (ARK Investment Management LLC, 2018)

In this section, cross-sectoral matching analysis based on trends of dominant companies for automotive and ICT sectors by researching their RDI strategies, strategic projects and/or products, cross-sectoral investments and acquisitions are presented. By researching dominant companies, the inner structure of market convergence is aimed to be examined, as well as its effects on the transformation of the dynamics of SIS. For the examined companies an AUTO-ICT cross-sectoral convergence is observed clearly; similar to the findings from international organizations and examined countries in previous sections. Prominent KETs for examined companies include, *CAVs, cyber-physical systems, intelligent mobility systems, vehicle operating systems, autonomous systems including 5G integration, IoT, M2M, human-machine (vehicle) interaction, AI and ML, in-vehicle communication and infotainment systems, big data, and cloud computing.*

While prominent KETs are transforming the entire value chain of respective sectors, creating and transforming knowledge and technology-bases, but also, market-base of the SIS by introducing new actors in the cross-sectoral perspective. Global market leader automakers are transforming into ICT-based companies, but mostly prefer mutual cross-sectoral national/international collaborations (such as open alliances, platforms, or development of strategic projects by using respective capacities, etc.) in order to pioneer the emerging AUTO-ICT sector and gain competitive advantage. It should be noted that, these collaborations are also creating a co-opetitive ecosystem,

in the sense of open partnerships and alliances by global market leaders, as well as niche market competitors, in mission-oriented projects; such as creating connected vehicles, or vehicle operating systems. In that regard, automakers are also investing heavily in the cross-sectoral perspective or founding subsidiaries for developing and branding the particular KETs, such as Google founding Waymo, an autonomous vehicle subsidiary; or Ford founding Ford Smart Mobility LLC, or Tesla acquiring DeepScale, a semi-autonomous & autonomous vehicle company. These cross-sectoral acquisitions (which are examined and presented in detail by using Crunchbase Database) are not only directed to in the cross-sectoral perspective of automotive or ICT based companies; but also include various related areas such as energy, advanced manufacturing, and materials. This perspective can also be observed from the cross-sectoral specific strategies of the companies, such as VW's "Transformation 2025+", Toyota's "Smart Mobility Society", and Tesla's "Energy Management Strategy".

On the other hand, one of the crucial points for the examined companies is that they are heavily investing in sharing economy, and developing digital business models. For example, GM's investment in Lyft to develop an on-demand network of self-driving vehicles or developing its own mobile brand, Maven, and creating an in-vehicle demand system. Alternatively, Toyota integrating transportation and mobility services by "i-Road" EVs. From the perspective of market convergence, one of the prominent findings suggests that examined companies are also strategizing over vertical integration, and relatively horizontal integration, and offering services in order to create entire ecosystems. Another point is that while the examined companies are targeting to become pioneers of the emerging AUTO-ICT sector, they are also addressing the challenge of designing standardizations for market formation.

It should be emphasized that, examined cross-sectoral investments, international collaborations, cross-sectoral projects are also bringing the co-evolutionary aspects in focus for both national and international markets. For example, automotive sector dominant actors are defining their primary industry as AUTO-ICT cross-sectoral areas. For instance, automakers targeting to become "mobility as a service" companies in the core, such as, while VW is targeting to become a "mobility service provider", Toyota

is defining itself as a “smart mobility company”, and alternatively Tesla is defining itself as an “automaker and software company”. The aforementioned remarks suggest a cross-sectoral co-evolutionary perspective in the global markets as well as the transformation of the respective SIS. These conclusions are evaluated and presented in Section 5.1.3.2, including Table 5.2 that shows a summary of results.

5.2. Qualitative Analysis

From now on, qualitative analysis is presented regarding results of expert review, which is obtained via a structured online survey.

5.2.1. Expert Review

First, scope and method sub-section, then analysis results and evaluation sub-section for qualitative analysis are given below.

5.2.1.1. Scope and Method

It is considered that to observe cross-sectoral dynamics, especially co-evolution, taking sectors separately and excluded from the convergence effect, is crucial. On the other hand, expert judgments are also considered valuable to analyze cross-sectoral co-evolution and to determine KETs. Therefore, for taking perspectives of sectoral experts and improve and/or strengthen quantitative analysis, a qualitative analysis is necessary. For this purpose, “Expert Review” is included as a part of the case study. A structured online survey (an online structured expert contribution form), using the cross-sectoral matching analysis method, is applied to distinguished sectoral experts from both automotive (AUTO) and ICT sectors, regarding cross-sectoral dynamics. The structured expert contribution form is prepared in order to reflect and gather information in the same context as quantitative analysis. Therefore, both sectors are put under evaluation separately. Same as, Section 5.1.1 Quantitative Analysis for Science Convergence, the cross-sectoral matching method based on TAs is applied as ICT-based AUTO sector and AUTO-based ICT sector, respectively.

On the other hand, the online survey is applied under the approval of METU Applied Ethics Research Center, Human Subjects Ethics Committee (Appendix F). For the determination of contributors, a pool of over a thousand distinguished sectoral experts from academia, private and public institutions, and the private sector is determined considering automotive and ICT sectors and their cross-sectoral dynamics, respectively. CEOs and senior experts from analyzed companies, and most frequent sectoral conventions, are invited. Moreover, TÜBİTAK project conductors who are respectively completed projects in cross-sectoral aspects, are regarded. “Limesurvey” is used as an online survey system. The online survey is applied bilingual, and consecutively for two months, between March and May 2019. The structured expert contribution form is organized as three main parts, two of them being compulsory, which are explained below (Figure 5.28);

- (1) **First part** is designed as a **compulsory** part, and sectoral experts are required to prioritize sub-technology areas of automotive and ICT sectors respectively while taking into consideration the cross-sectoral and convergence dynamics. In this regard, a prioritization technique with a score of 1-5, is applied.
- (2) **Second part** is designed as an **optional** part, and Delphi Technique is applied. Sectoral experts are required to submit Delphi statements (or target statements) for the evaluation of cross-sectoral and convergence dynamics. While it is optional, at least one Delphi statement is kindly requested. For this purpose, sample Delphi statements are also provided.
- (3) **Third part** is designed as a **compulsory** part. Sectoral experts are required to evaluate the interaction between automotive and ICT sectors considering the types of convergence and if it is co-evolutionary. Questions are designed in order to observe the evaluation of sectoral experts whether the automotive and ICT sectors are transforming one-sided or two-sided. Or, what kind of convergence has the most impact on the cross-sectoral and co-evolution dynamics regarding automotive and ICT sectors. In this regard, a scaling technique with a score of 1-10, is applied.

**FOR THE SUCCESS OF THE CONTRIBUTION FORM,
PLEASE TAKE THE FOLLOWING IN CONSIDERATION.**

The form consists of three studies, two of them being compulsory.

STUDY 1: PRIORITIZATION OF CROSS-SECTORAL TRENDS BASED ON SUB-TECHNOLOGY AREAS FOR BOTH SECTORS (COMPULSORY)

- Prioritization of sub-technology areas of **Automotive and ICT sectors** respectively, taking into consideration the cross-sectoral dynamics (prioritization technique with a score of 1-5)

Scoring is required for both sectors separately.

1.A. INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT)

1.B. AUTOMOTIVE

Sample Figures:

1.A. ICT Sub-Technology Areas Based Prioritization

Only numbers may be entered in these fields

1. Information Security (Including Cyber Security)		
2. Cloud Computing (Including Virtualization and High Performance Computing)		
3. Digital Content and Internet Technologies		
4. Display Technologies		
5. Photonics		
6. Broadband Technologies (Including Wired/Wireless Communication Technologies, IP Technologies and Telecommunication)		
7. Embedded Systems		
8. Power Electronics		
9. Micro/Nano/Opto-Electronics Technologies (MEMS, NEMS, MOEMS)		
10. Semiconductor Technologies and Integrated Circuits		
11. Mobile Communication Technologies (Including Internet of Things and M2M related areas)		
12. Robotics and Mechatronics Systems		
13. Software Technologies (Including Mobile Apps, Open Source Software, Animation and Game Technologies)		
14. Data Processing, Storage and Protection Technologies (Including Signal, Image, Video and Speech Processing)		

1.B. Automotive Sub-Technology Areas Based Prioritization

Only numbers may be entered in these fields

1. Automotive - Battery Technologies		
2. Electric and Hybrid Vehicle Technologies		
3. Automotive - Material Technologies		
4. Engine and Powertrain Technologies		
5. Automotive - Embedded Systems		
6. Vehicle and Component Innovative Design and Design Verification Technologies		

STUDY 2: COLLECTION OF TARGET (DELFI) PHRASES FOR THE ANALYSIS OF CROSS-SECTORAL TRENDS (OPTIONAL)

THIS SECTION IS OPTIONAL HOWEVER IT IS REQUESTED THAT AT LEAST 1 TARGET PHRASE IS WRITTEN.

- Collecting target statements for the evaluation of cross-sectoral dynamics (delfi statement technique)

Sample Target Phrase 1: Designing communication units using FPGA and DSP processors that can support the 802.11p standard and provide location information with 99.9% accuracy in vehicles by the year 2023.

Sample Target Phrase 2: Developing embedded systems (smart sensors) using conventional sensors and / or newly designed sensors in the areas of control, navigation, power management, etc. for the automotive sector.

STUDY 3: PRIORITIZATION OF CROSS-SECTORAL TRENDS BASED ON CONVERGENCE TYPES FOR BOTH SECTORS (COMPULSORY)

- Evaluating the dimensions of the interaction between Automotive and ICT sectors considering the types of convergence (if sectors are transforming one-sided, or what kind of convergence has the most impact, etc. Weighting technique with a score of 1-10)

Scoring is required for both sectors separately.

Sample Figure:

	Science (Knowledge) Convergence	Technology Convergence	Market Convergence
What convergence type is the most impactful in terms of AUTOMOTIVE sector on ICT sector?	7	8	9
What convergence type is the most impactful in terms of ICT sector on AUTOMOTIVE sector?	8	10	6

Figure 5.28. Summary of the Expert Contribution Form

5.2.1.2. Analysis Results and Evaluation

A total of forty-two full responses out of a hundred and thirty-five semi-full/limited are examined. Since a very specific expert opinion was aimed for the analysis, and the distribution of full responses is regarded as well balanced for the pool regarding the type of organizations and type of sector, the contribution of solid forty-two experts are considered as significant.

Figure 5.29 presents the distribution of the contributors, by type of organization as the top series including the size of organization for the private sector and by type of sector as the inner series. The distribution of contributors by type of organization shows that the concentration for the private sector is higher than university (76% and 17%, respectively). However, private sector contributors also have academic backgrounds, and also contributors from universities have private sector experience (including spin-off founders) as it is gathered from their provided personal information. Additionally, very limited contributions from public institutions are obtained. Moreover, in order to gather more information on the contributors' or organizations' expertise regarding cross-sectoral dynamics, phone call based interviews are conducted and Crunchbase Database is used. In addition, looking at the distribution of contributors from the private sector by the size of the organization, it can be seen that SMEs' share is slightly higher than big companies.

Accordingly, looking at the distribution of contributors by type of sector, ICT sector concentration is observed higher than the AUTO sector (36% and 17%, respectively). More appropriately, 26% of the contributions are obtained from organizations/academicians working in both the automotive and ICT sectors (AUTO-ICT sector), mostly regarding autonomous vehicles, self-driving technology, connected vehicles, and related technologies (M2M, V2V, AI, ML, etc.) and vehicle software technologies, including embedded systems. The concentration of other sectors is relatively high (21%). However, this result does not change the well balanced distribution of contributors, because the contributors from other sectors are either directly related to ICT and/or automotive sector, or from related sectors such as energy

(for instance, wireless charging technology for EHV), advanced manufacturing and advanced materials, working actively on the automotive sector, and experienced about digital transformation.

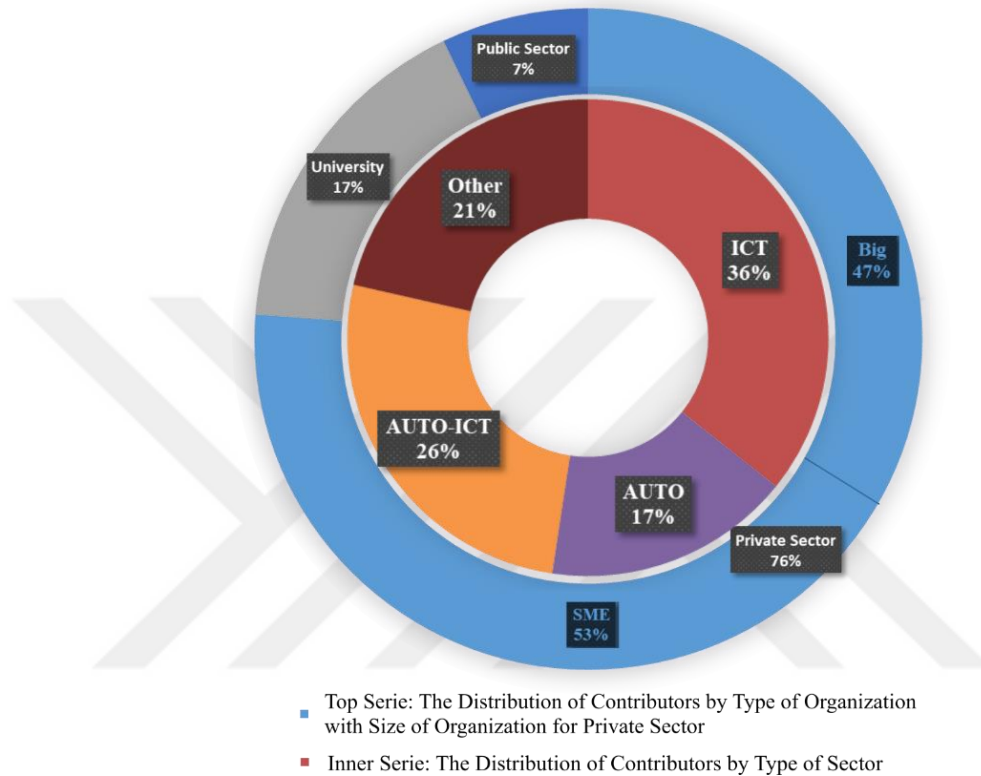


Figure 5.29. Distribution of Contributors of the Expert Review

Firstly, sectoral experts are asked to prioritize sub-technology areas of automotive and ICT sectors, respectively, while taking under consideration the cross-sectoral dynamics. Figure 5.30 presents the Sankey diagram made by Sankeymatic for prioritization of sub-technology areas, respectively, based on the sum of assessment scores of sectoral experts. From the perspective of contributors, for the ICT-based AUTO sector, embedded systems, robotics and mechatronics (including AI), data technologies, mobile communication technologies (including IoT and M2M), and power electronics are evaluated as the most impactful sub-technology areas for the cross-sectoral convergence. Accordingly, embedded systems, battery, and EHV technologies are the most impactful sub-technology areas for the AUTO-based ICT sector.

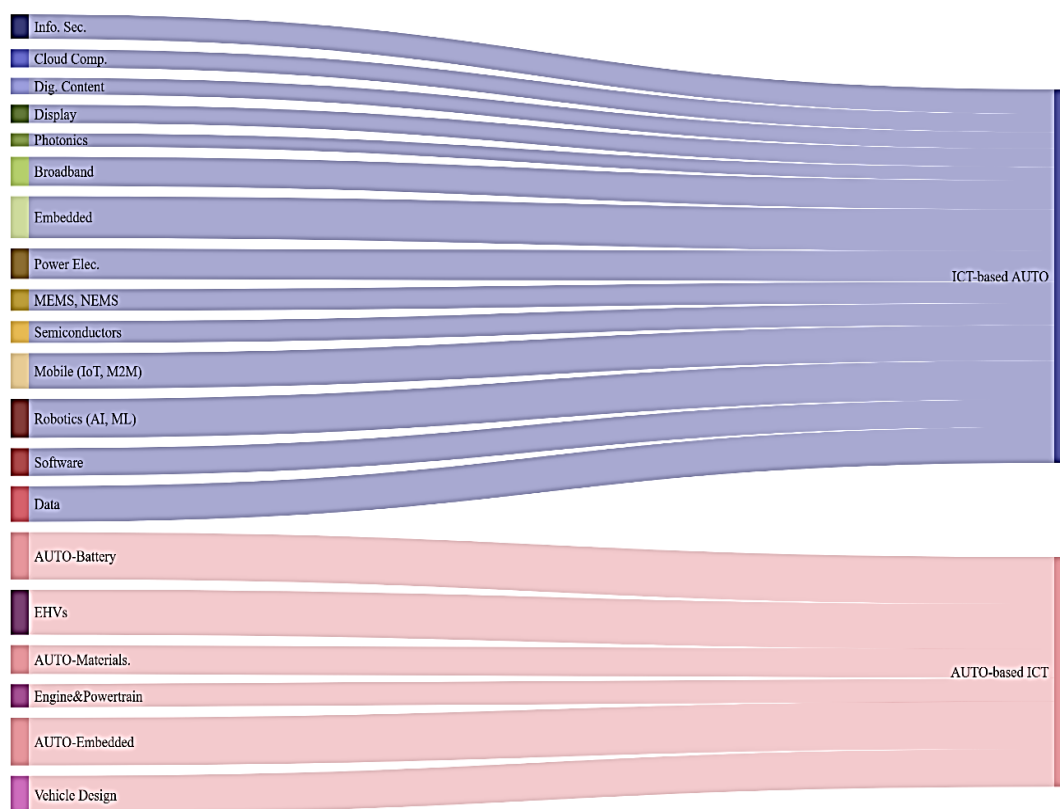


Figure 5.30. Sankey Diagram for Prioritization of TAs for ICT-Based AUTO Sector and AUTO-Based AUTO Sector

Secondly, however optional, Delphi statements are collected to analyze out-of-the-box and other conceptual opinions. Delphi statements support the findings above. Forty-two contributors submitted forty-nine Delphi statements. Figure 5.31 shows the keyword cloud for the prioritized sub-technology areas and KETs from the Delphi statements, using text mining method, and computation of relevance and co-occurrence scores, via Semantia. As can be seen from the figure, autonomous vehicles and connected vehicles (including V2V, V2I, V2X, M2M, human-machine interaction, AI, ML, image/video processing) are prominent KETs both by relevance and co-occurrence scores. Evidently, in accordance with the findings of the previous sections presenting quantitative analyses, these KETs can be considered as the main KETs for the emerging AUTO-ICT sector, as well as the emerging sector per se. For instance, it can be suggested that autonomous vehicles are a separated and converging sector for the automotive and ICT sectors. On the other hand, electric and hybrid-

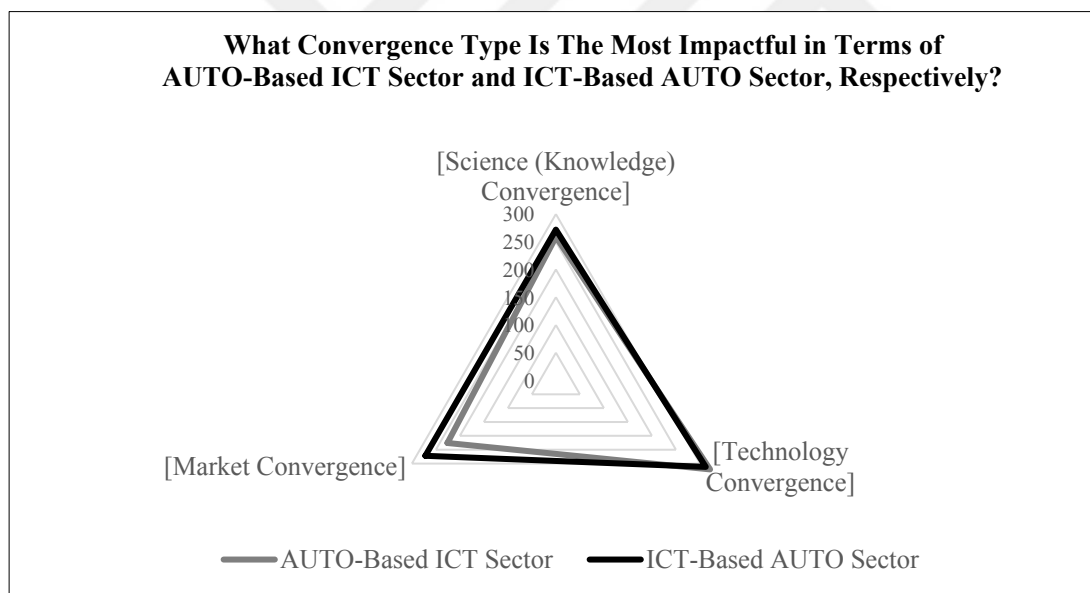
electric vehicles (EVs, HEVs) together, are also concentrated KETs. Relatively and relatedly, safety and security technologies for vehicles, self-driving technology, Advanced Driving Assistance Systems (ADAS), battery technologies, together with energy storage systems and power management systems, vehicle operating systems and vehicle software, embedded systems and software, are highly targeted KETs for the emerging AUTO-ICT sector. In addition, along with the KETs smart mobility is also featured by sectoral experts. Furthermore, there are several prominent policy remarks that, sectoral experts pointed out in the Delphi statements. These are the necessity of adapting new regulations in accordance with the rapidly converging technologies and industries. Especially regarding international environmental protection norms (Paris Declaration, etc.) and standardization requirements. Particularly with regard to standardization, proactive regulations are required in order to dominate the global market and develop niche areas as pioneers, for market formation.

Lastly yet importantly, advanced materials and light weight vehicles are also targeted by sectoral experts. Accordingly, it is also stated that especially in 2025 and beyond, the convergence trend is expected to be more disruptive, and today's emerging sectors, for instance, AUTO-ICT sector, and KETs will be much more dominant for the economies, that in turn, today's sectoral boundaries will not exist. These results present the correlation with the context and evaluation of quantitative analysis (Section 5.1) results, conducted in the previous sections.



Figure 5.31. Keyword Cloud for Delphi Statements

Finally, taking into consideration the cross-sectoral dynamics, evaluation of convergence types is requested from sectoral experts. Both for ICT-based AUTO sector and AUTO-based ICT sectors, technology convergence is evaluated as the most impactful, while science and market convergences are also seen as correlated. Both results can be seen in Figure 5.32. While science and market convergences are regarded as impactful in a more balanced way and more closely related to technology convergence when it comes to ICT-based AUTO sector; in the case of AUTO-based ICT sector, science and market convergences are regarded as less impactful and distantly related to technology convergence, this means that, while there is a two-sided co-evolutionary process regarding both sectors, ICT sector is affecting the automotive sector in all types of convergences, while automotive sector is affecting ICT sector mostly on the technology convergence, then science and lastly market convergences.



Note: Axis demonstrates the sum of the scaling between 1-10 from the expert survey.

Figure 5.32. The Most Impactful Convergence Type for Cross-Sectoral Co-Evolution

5.3. Further Remarks of the Case Study for the Concept of CSIS Approach

The findings of the analyses, while having limitations, show that automotive and ICT sectors are transforming in a co-evolutionary way based on technology convergence (mutually affected by science and market convergences) and an emerging AUTO-ICT

sector is in process. It may be expected that both sectors merge and define a sector on their own. Alternatively, one of the KETs may form an individual sector, reflecting both sectors, such as CAVs, or autonomous vehicles. The results of this thesis reveal that both scenarios are probable.

In the first scenario, can a newly defined sector (AUTO-ICT) be still examined and/or evaluated by the SIS approach? From the results of the case study, it can be suggested that SIS approach would fall short to integrate continuous converging effects. For instance, in the case study, automotive and ICT sectors showed mutual dynamics, common knowledge, technology, and market-bases, or shifts of bases. To explain it better two Sankey diagrams are prepared based on sub-technology areas of both sectors. All scores of sub-technology areas in the cross-sectoral matching analysis method, including results of both quantitative and qualitative analyses, are normalized. Firstly, ICT-based AUTO and AUTO-based ICT sectors are given respectively in Figure 5.33 and Figure 5.34, together forming an AUTO-ICT sector. Figure 5.33 shows sub-technology areas and Figure 5.34 showing (selected) emerging KETs. For ICT-based AUTO sector, the result of the case study indicates that power electronics is the most impactful for cross-sectoral convergence, following by semiconductors and mobile communication technologies (including IoT and M2M). Whereas for AUTO-based ICT sector, EHV technologies are the most impactful, followed by engine and powertrain technologies, automotive embedded systems, and automotive battery technologies; which are also closely related regarding the knowledge and technology-bases. This means that, EHV can be observed as a separated sector with related sub-technology areas, which are converging.

In this regard, in Figure 5.35 relatedness of the sub-technology areas in the cross-sectoral perspective is also shown via Sankey diagram. Relatedness shows how each sub-technology area of ICT-based AUTO sector and AUTO-based ICT sector is affecting each other respectively and how impactful they are in the forming and/or transforming the emerging AUTO-ICT sector. This logic is applied as a relatedness metric and presented in Figure 5.35. For instance, while power electronics and EHV are 100% related in terms of knowledge, technology and market-bases; engine and

powertrain technologies are almost equally related to power electronics and semiconductors, as well as related to robotics and mechatronics (including AI, ML) and embedded systems to a lower degree.

Building upon these facts, it can be speculated that sector-specific conditions determine the extent of cross-sectoral heterogeneity; however, if more than one dominant sector is taken in focus there can also be observed homogeneity to an extent. On the other hand, in the case of a new sector, there would still be relatedness between KETs, considering the disruptive impact of convergence. Therefore, a necessity for CSIS approach as framework and methodology would still be required complementary to the current IS approaches.

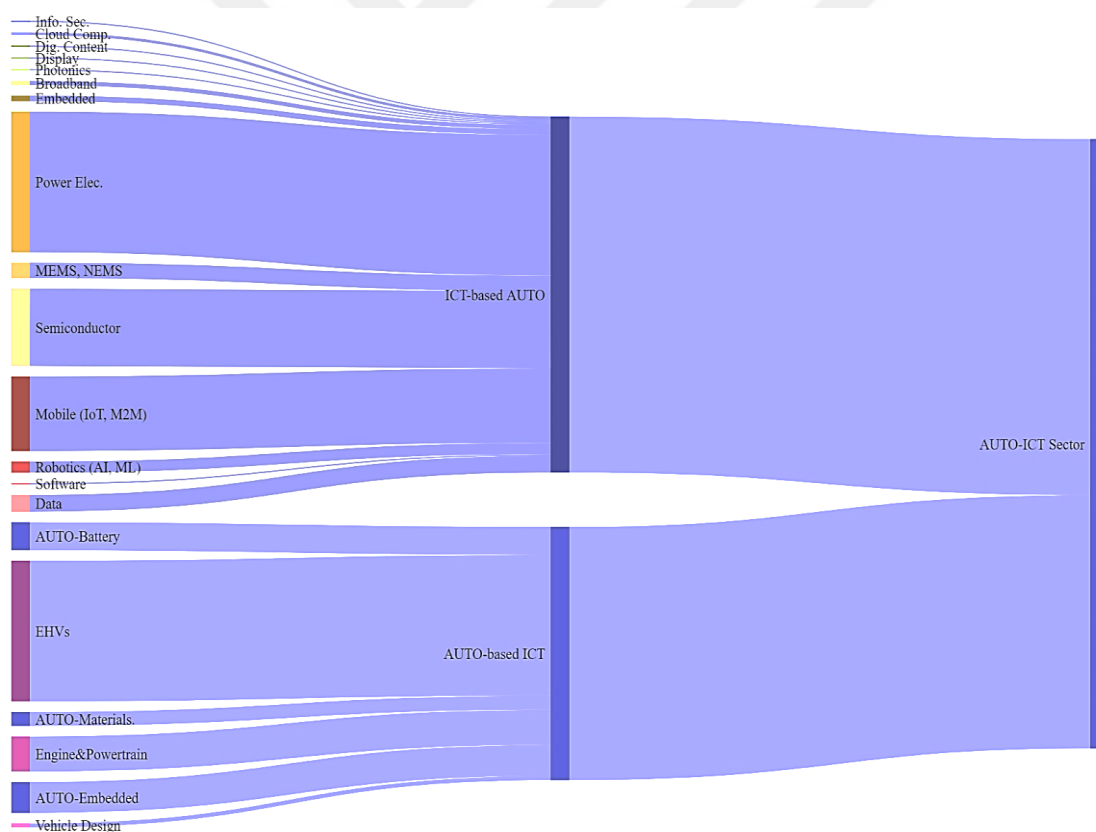


Figure 5.33. Sankey Diagram for TAs Based On Normalization of Total Analysis Scores

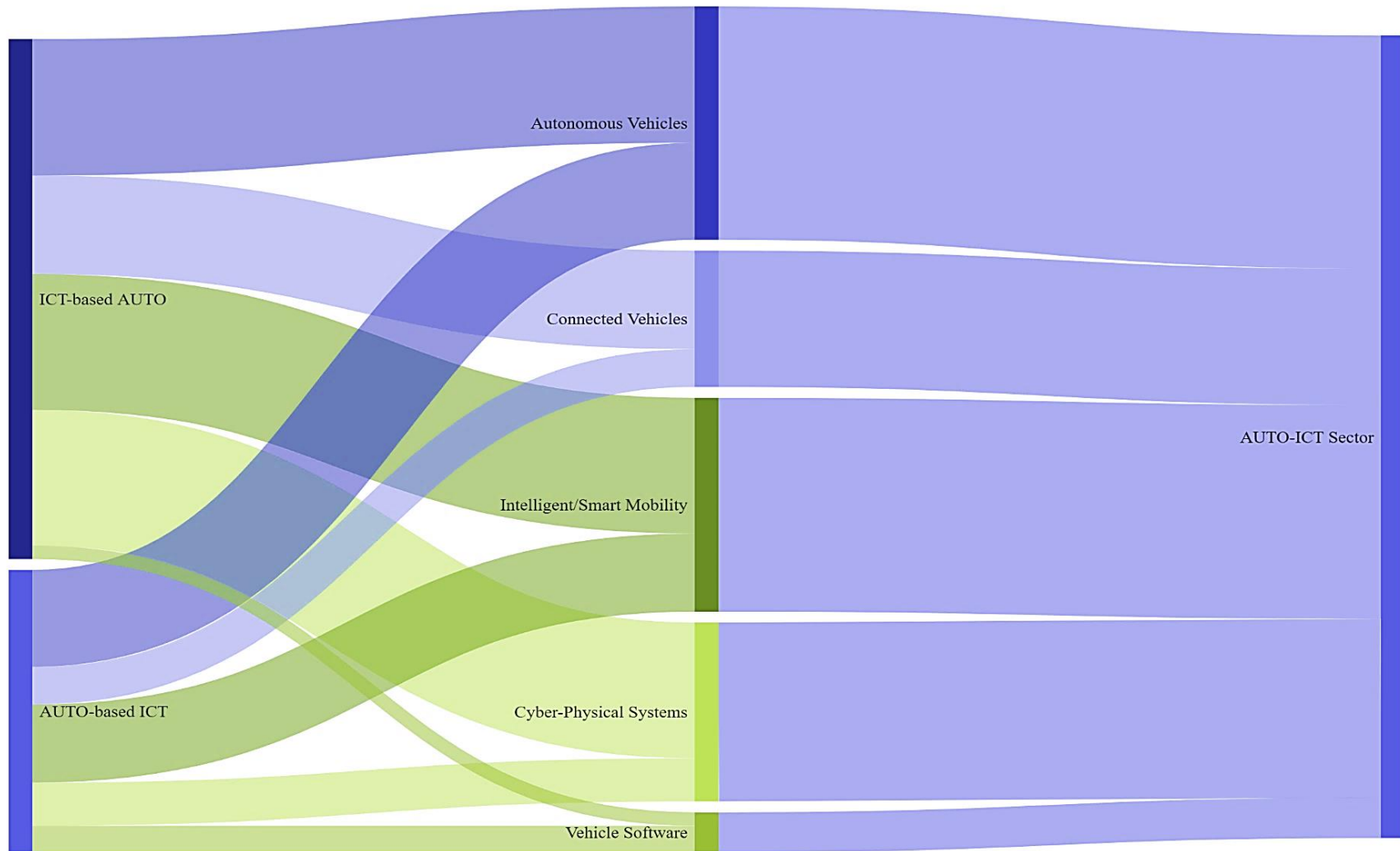


Figure 5.34. Sankey Diagram for Emerging KETs Based On Normalization of Total Analysis Scores

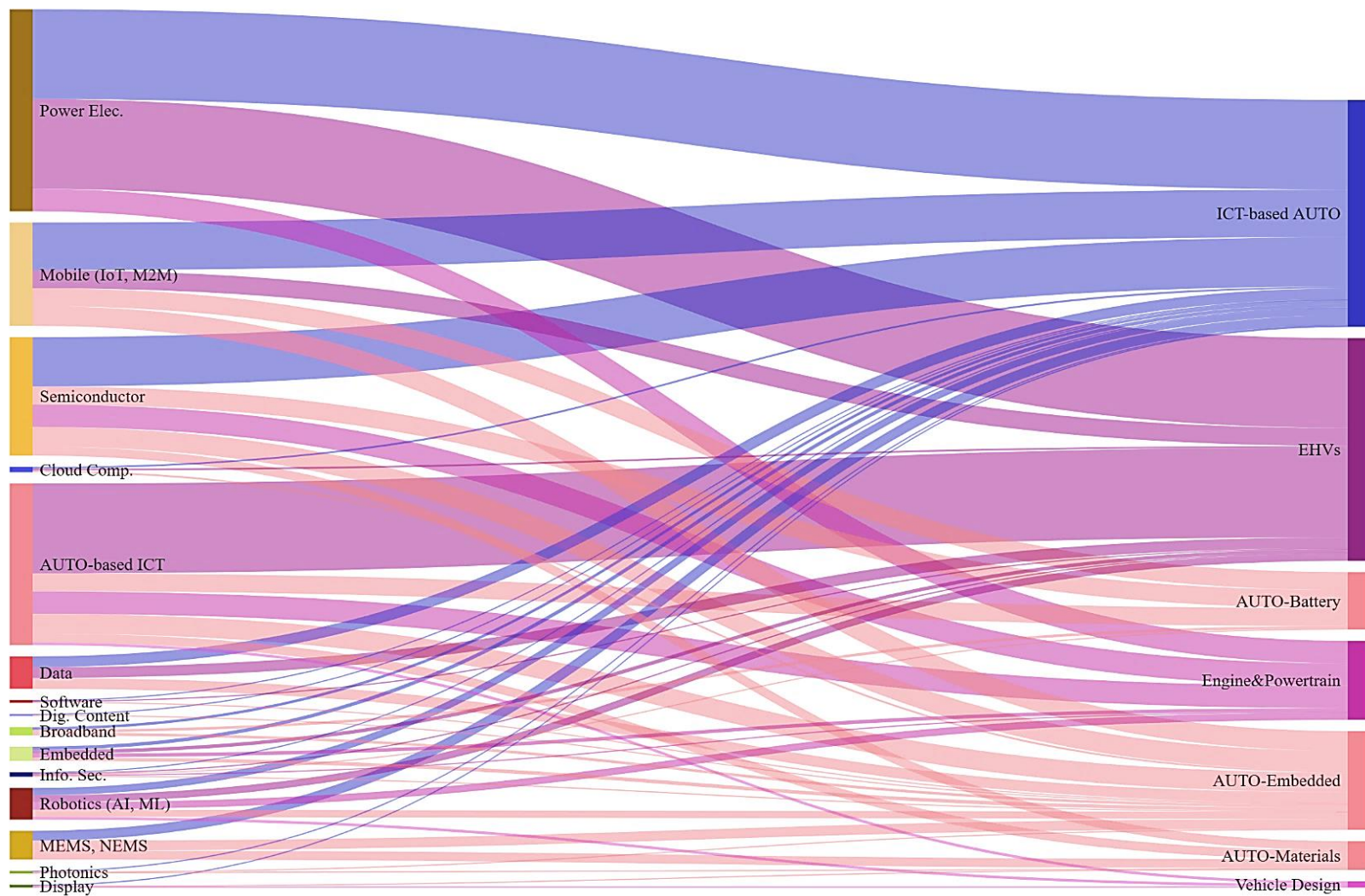


Figure 5.35. Sankey Diagram for Relatedness of Automotive and ICT TAs

CHAPTER 6

CONCEPTUALIZATION OF CROSS-SECTORAL INNOVATION SYSTEMS

In this chapter Cross-Sectoral Innovation Systems (CSIS) approach is conceptualized based on the outcomes of “Theoretical Background” (Chapter 2) and “Descriptive Study” (Chapter 3), accordingly benefitting from the findings of the “Case Study” (Chapter 5).

Recent advancements indicate that one of the most impactful changes in the economies, businesses, and innovation systems are based on the disruptive effects of convergence, particularly technology convergence and hereby, industry convergence, where sectoral boundaries blur, and systemic dynamics transform rapidly and even defined from scratch. Accordingly, there is a shift in focus from the vertical integration of individual products to the horizontal integration of cross-sectoral value chains. It should be emphasized that as it is shown by the previous chapters, this trend is growing, while the abovementioned cross-sectoral transformation process is not evaluated by any methodology nor examined from the perspective of the innovation systems (IS) literature. More specifically regarding sectoral innovation systems (SIS), convergence, especially technology convergence, has been regarded as the major source of innovations among sectors and technologies. On the other hand, interdependencies and complementarities define the real boundaries of a sectoral system, and a dynamic co-evolutionary process within the “sector” is investigated (Malerba, 1999, 2002). In this regard, a systematic and broad understanding of technology convergence is important in pursuing continued innovation and economic growth (Lee, 2015).

SIS approach particularly pays attention to the links and interdependencies of one dominant sector and does not focus on and/or analyze related/supportive sectors

directly. Current IS approaches are limited in the perspective of cross-sectoral co-evolution, and convergence trend; however, they can be used as the basis of further examination and analysis. There are three main findings that current IS approaches also draw the attention to CSIS approach, these are as the following:

- (1) Focus on dynamics of only one dominant sector and co-evolution within its own dynamics.
- (2) Pay attention to the links and interdependencies of related (supportive) sectors.
- (3) Remain inadequate to explain cross-sectoral dynamics based on the impact of technology convergence.

By integrating convergence with ongoing innovation system (IS) studies, a better understanding of the cross-sectoral dynamics can be observed. Additionally, by doing this, it is aimed to understand if there is a co-evolution between sectors while developing a methodology to analyze and conceptualize CSIS approach as a contribution to the IS literature and evaluation methods.

For this matter, the missing points in the current innovation system literature have been examined to determine the effects of technology convergence over co-evolution of more than one dominant sector, and the view of CSIS approach is determined. Literature review findings and comparisons of the IS literature regarding cross-sectoral and co-evolutionary perspectives revealed that there is a lack of understanding and evaluation methods regarding the transformation of new sectors and their dynamics in the cross-sectoral and co-evolutionary perspectives in the current IS studies (Table 2.1). Moreover, market and sector formations are reviewed as directly related to push & pull dynamics, as well as the formation of KETs. Accordingly, descriptive research on converging industries and industry convergence showed that cross-sectoral convergence is composed of broad transformation from knowledge-bases to technology-bases and market-bases, respectively. Especially in science and technology-driven sectors like the telecommunication or the pharmaceutical sectors, a convergence of technologies often becomes a decisive part of industry convergence. In addition, even when the dominant sectors are examined separately within their own

SIS dynamics and excluded from convergence effects, cross-sectoral convergence is observed. On the other hand, another crucial input of the descriptive study is the selection of the automotive (AUTO) and ICT sectors for the case study (Figure 3.5). IS literature and convergence literature are reviewed also for the measurement methodologies. While there are several approaches such as networking, community and clustering evaluation methods for measuring the performance of IS (Table 4.1), and bibliometric and mapping analysis methods for measuring and observing convergence, by the type of convergence (Table 4.2), they still lack in bringing a holistic approach to analyzing cross-sectoral perspective, co-evolution, and convergence.

The proposed CSIS approach examines the cross-sectoral, interdependent, and co-evolutionary relationships within dominant sectors that converge together (or are affected by convergence) and can alter similar components in national, sectoral, regional, and even wider global innovation systems. Accordingly, a cross-sectoral matching analysis method is introduced (Chapter 4, Figure 4.2, Table 4.3) and conducted for automotive and ICT sectors (Chapter 5).

Case study findings show that **sectors do not act as supportive and/or related sectors as the current SIS approach suggests especially regarding the convergence effect (particularly technology convergence)**. From the beginning, the cross-sectoral aspect was more clear to the eye, but the case study also showed that sectors, and especially dominant sectors such as automotive and ICT, are also converging as an innovation system and in a mutually co-evolutionary way. Dominant actors and their knowledge, technology and market-bases are shifting towards distinct dominant sectors. Boundaries of sectors blur and sectors obtain dynamics of each other. While knowledge and technology-bases may show dynamics of both sectors, market-base, firms and other actors co-evolve in having the dynamics of the converged sector. This transformation process may even form a new sector. A shift from vertical disintegration to horizontal integration in the value and supply chains has been observed as another emerging trend. Therefore, all such shifts and convergences observed by the case study indicated a co-evolutionary perspective, that both sectors

are triggering each other's transformation in terms of convergence types, most impactful via technology convergence. In this regard, considering SIS approach features and integrating them into CSIS approach, Figure 6.1 presents the comparison of the SIS and CSIS approaches. A major difference of the CSIS approach is that supported/related sector is considered as the main component of the system that should be evaluated in a cross-sectoral matching analysis. Therefore, there is more than one dominant sector in the CSIS approach.

SIS differs greatly in terms of the knowledge-base and learning processes related to innovation. First, knowledge may have different degrees of accessibility (Malerba and Orsenigo, 1997; Malerba, 1999; Malerba and Mani, 2009), for example, opportunities of gaining knowledge that are external to the firms. This knowledge may be internal to the sector (thus favoring imitation) or external to the sector (thus affecting the availability of technological opportunities to incumbents and new firms). In both cases greater accessibility of knowledge decreases sectoral concentration, however, the sector keeps its context-specific dynamics and co-evolution happens within the sector actors and dynamics. Considering these dynamics in the perspective of CSIS, sectoral boundaries become blurred by the effect of convergence. Thus, the knowledge flow is always both internal and external in a cross-sectoral perspective. In addition, the sectoral concentration is co-evolutionary in a cross-sectoral perspective. The dominant sectors transform, evolve, and absorb the dynamics of the converging technologies (KETs) and converging industries.

While a sectoral system has a knowledge-base (including aspects of a technology-base) in the SIS approach and key links and complementarities among products, knowledge and technologies, which greatly affect the creation, production and use of the “sectoral products”, there are additional aspects in the CSIS approach. Besides knowledge-base, technology and market-bases are determined separately, differentiated from each other to reflect the effects of each convergence type. During the cross-sectoral convergence process, a shift is observed between these three bases of the dominant sectors. However, while converging, the knowledge and technology-

bases are keeping their separated structure, whereas a common market-base is structured, even though the demand might be the same or different.

This difference between SIS and CSIS is also observed for networks and institutions. For instance, from the results of quantitative analysis of science convergence (Section 5.1.1.2) regarding automotive and ICT sectors, a shift is observed from ICT dominant actors towards AUTO dominant actors, and vice-versa, while AUTO and ICT dominant actors are keeping their respective knowledge-bases. Accordingly, from the results of the quantitative analysis of technology convergence (Section 5.1.2.2), dominant actors are observed to specialize under their dominant sub-technology areas and transform the corresponding sector (co-evolution). This means that, for instance, while dominant actors of AUTO sector are specializing in the ICT sector; dominant actors of the ICT sector are specializing regarding AUTO sector requirements, and technology-bases are merging. This observation reflects to market-base as an individual structure. For instance, from the quantitative analysis of market convergence (Section 5.1.3.2), personalization demand might form a market-base for in-vehicle applications integrated with smartphones. In this case, the demand is AUTO-based ICT sector; however, market-base is for the emerging AUTO-ICT sector.

Furthermore, same as market-base, firms and other actors are changing their structures in order to reflect cross-sectoral convergence. For instance, several AUTO sector dominant actors define and vision themselves as the emerging AUTO-ICT sector dominant actors, while specific ICT sector dominant actors vision a leadership in global market of the emerging AUTO-ICT sector, and investing accordingly. In addition, while dominant actors are observed to enable cross-sectoral co-evolution regarding all convergence types, they are also causing a shift of knowledge-base towards technology and market-bases. From this perspective, the co-evolutionary aspects of the SIS approach are reflected in the CSIS approach as well. It should be emphasized that as their product lines and strategic investments differ to realize the abovementioned cross-sectoral vision, the vertically integrated structures also transform into horizontally integrated structures. The transformation process of the

respective dynamics of both upper and inner structures of market convergence also transforms the dynamics of SIS and NIS (partly RIS), in turn.

In addition, the qualitative analysis supports the results of quantitative analyses, while also indicating an additional perspective regarding co-evolution and convergence types. While there is a two-sided co-evolutionary process regarding both sectors, the ICT sector is affecting the automotive sector in all types of convergences, while the automotive sector is affecting the ICT sector mostly on the technology convergence, then science and lastly market convergences (Section 5.2.1.2, Figure 5.32). Consequently, all shifts and convergences explained above, indicate a co-evolutionary perspective, that both sectors are triggering each other's transformation most impactful via technology convergence.

On the other hand, in SIS approach where firms are more constrained by technological regimes underlying sectoral evolution, the driving forces behind technological evolution are found at both the firm and sector level, but in different degrees (Clausen, 2013). Unlike SIS, CSIS might evolve homogeneously. Sectors differ in terms of innovative activities, interdependent constituents and dynamics, however in perspective of convergence and its effects on different sectors show cross-sectoral homogeneity. In addition, none of the sectors is dominated by a single technological regime; there are more than one key enabling technologies (KETs) that transform the sector and its dynamics, and effects the boundaries of the sectors. Therefore, it is also important to determine KETs in evaluating the co-evolution of cross-sectoral dynamics. With the effect of convergence and KETs, the sectors show different dynamics from other distinct sectors. From the result of the case study, the formation and impacts of KETs are also observed two-sided, this means that while the cross-sectoral convergence triggers the formation of KETs, existent KETs also cause cross-sectoral convergence. It should be noted that, these particular cases might differ for other sectors; on the other hand, the findings of the descriptive study and case study are reflected in Figure 6.1.

As a result, CSIS approach is a dynamic structure that emerged from the interdependent constituents of two or more dominant sectors that co-evolve and transform each other in linear or non-linear ways via the disruptive impact of convergence in the knowledge, technology and market-bases. Accordingly, CSIS approach analyzes the cross-sectoral, interdependent, and co-evolutionary relationships within more than one dominant sector that converge together and can alter similar components in the innovation ecosystem. Therefore, **CSIS approach can be defined as a framework of cross-sectoral distinct institutions whose interactions contribute jointly to the production and innovation processes of more than one converging dominant sector which may even evolve into a completely new sector.**

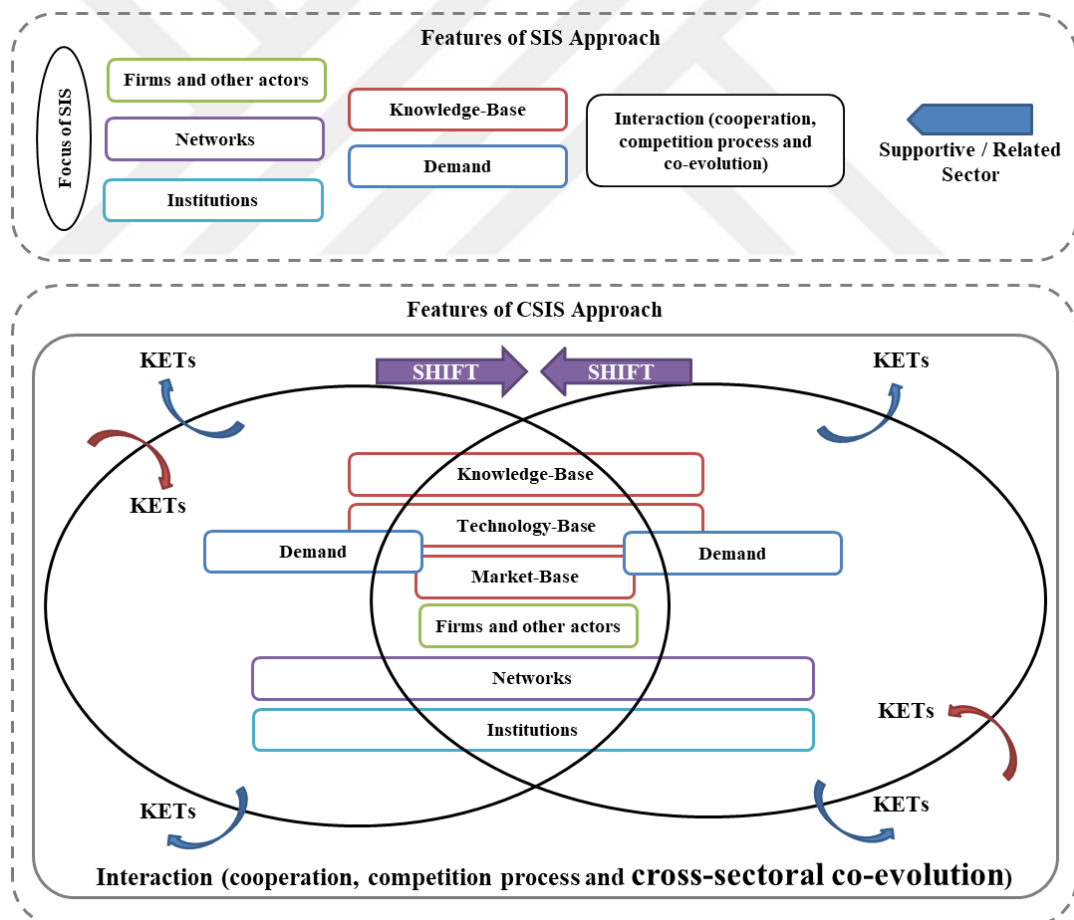


Figure 6.1. Comparison of Features of SIS and CSIS Approaches

In accordance with the results, the conceptualization of CSIS approach is depicted in Figure 6.2. Left side of the figure shows the main drivers of CSIS, which are convergence (knowledge, technology and market), shift of knowledge-bases (including technology and market), emergence and disruptive impact of KETs, and cross-sectoral co-evolution. In the middle of the figure, CSIS approach is shown by detailing the process of formation of new sectors and/or new economy models by the disruptive effect of convergence, which are also shown as cross-sectoral shifts between more than one dominant sectors. Cross-sectoral shifts result as sectoral boundaries getting blurry, and knowledge/technology and/or market-bases transforming. On the other hand, the definition of “sectoral” product change, and it involves aspects of more than one dominant sector, such as a manufacturing-based sector having a service-based product (service as a product).

As suggested before, value and supply chains of the sectors also transform, mainly vertical chains become horizontal. Moreover, end-users are important actors in the CSIS approach. They do not just demand but also interact with the producers, and/or become producers (prosumers). Additionally, changes in the innovation systems are also detailed. For example, blurry boundaries of sectors also reflect as blurry boundaries of respective innovation systems. Vertical chains become horizontal that emerges the need for inclusive and cross-sectoral collaboration models that include the central role of new actors, such as end-users, and/or cross-sectoral, multi and interdisciplinary skills and aspects. This observation also leads to inclusive knowledge exchange and/or collaboration model, namely co-creation.

Lastly, in accordance with the formation of new sectors and changes in innovation systems; barriers that are faced in the case of cross-sectoral approaches are given on the right side of Figure 6.2. Such as lack of understanding and focus on cross-sectoral approaches, lock-ins and path dependency, lack of adoption of KETs, lack of funding for multi and interdisciplinary areas, infrastructures, skills, etc. These barriers should be addressed by policy implications and measures, which are discussed in Section 7.2, Chapter 7.

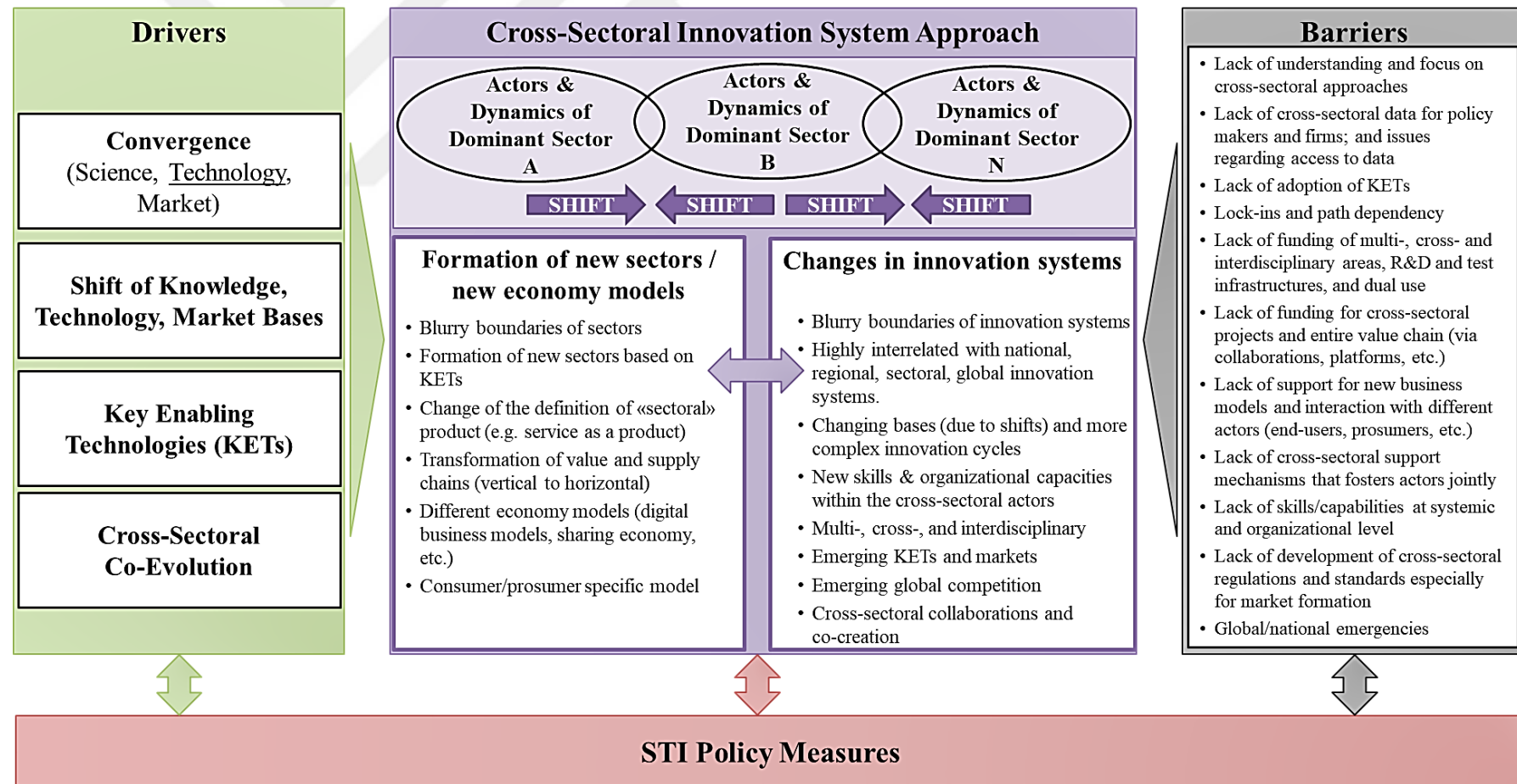


Figure 6.2. Conceptualization of CSIS Approach

CHAPTER 7

CONCLUSION

The main goal of this thesis, designated as the main research question, is to examine whether there is a cross-sectoral co-evolution process based on convergence from the perspective of innovation systems (IS) approach. Additionally, two auxiliary research questions emerged and were studied. First, the identification of gaps in the current innovation system literature to determine the effects of technology convergence over co-evolution of more than one dominant sector. Second, the advantages of the dynamics that are related to the formation of “Key Enabling Technologies (KETs)” based on the conceptualization of the cross-sectoral co-evolution.

For this matter, first, a literature review and in complementary a descriptive study are prepared. The findings of both studies showed the necessity of a methodology and a framework that focus on cross-sectoral dynamics with the perspective of IS approaches while integrating with technology convergence trend. Accordingly, an analysis method is proposed, while benefitting from the current methodologies. With the proposed analysis method, a case study is conducted for the automotive and ICT sectors, including both quantitative and qualitative technics. The findings of the descriptive study also contributed to the selection of automotive and ICT sectors for the case study. As a result, findings of literature review, descriptive study, and case study all contributed to the conceptualization of the framework for cross-sectoral dynamics that focuses on more than one dominant sector, as complementary to the current IS approaches.

In the following sections, the key findings of the thesis with the context of the aforementioned studies, suggested policy implications, and further remarks are presented, respectively.

7.1. Key Findings of The Thesis and The Concept of CSIS Approach

In accordance with the research questions, technology convergence, cross-sectoral co-evolution and industry convergence are investigated in the perspective of current IS approaches (NIS, RIS, SIS, CIS) for the literature review. Later on, a descriptive study is held regarding the terms “converging industries” and “industry convergence” for a comprehensive understanding of cross-sectoral convergence. The findings of the descriptive study are also used as inputs for the selection of the sector for the case study. From the literature review and descriptive study, it is observed that convergence, especially technology convergence, is disrupting the foundations of sectors and dynamics of the respective IS. As a rapidly advancing trend, technology convergence decreases the threshold of transforming the dynamics of respective IS, while becoming the driver for the new economy and innovation systems. IS literature focuses on technological change through a technological evolution analysis. From the perspective of IS literature, while its importance and effects are recognized, convergence and its disruptive impacts are considered as the inner dynamics of the respective IS, and evaluated as such. Additionally, while it is assumed that sectors are composed of more than one technology, they are accepted as interdependent and complementary. Also, it is accepted that sectors co-evolve with their institutional environment, it is also stated that sectors are affected in terms of their performances by the presence of dominant supportive/related sectors. For example, SIS perspective suggests that links and complementarities are defined between the dominant sector and a related/supportive sector that heterogeneity within sectors is a key element.

Therefore, technology convergence and its impacts on sectors and innovation systems emerge as one of the critical issues for improvement in both conceptual and methodological manner. In order to understand cross-sectoral dynamics better, there

is a need for improvement towards an approach where the links and complementarities that define sectoral boundaries are addressed from the perspective of more than one dominant sector. In addition, IS literature and convergence literature are observed to be very disintegrated, even for observing the transformation of the KETs and sectors, and their dynamics in the presence of disruptive convergence effect. For instance, while the notion of “industry/sector” itself rapidly changes and innovation is accepted to be a consequence of an intense intersection of more than one dominant sector, current IS approaches remain open for development in terms of observing and a better understanding of such dynamics. Accordingly, literature review findings mapped by nine criteria and a comparison table (Table 2.1, Chapter 2) is prepared to show the benefits of developing a cross-sectoral innovation system (CSIS) approach. Used nine criteria for comparison are as the follows; Definition / Main Unit of Analysis; Boundaries of the Sector/ Relation Between Different Sectors; Focus on Technology Convergence; (Cross-Sectoral) Co-Evolution Perspective; Focus on Industry Convergence; The Emergence of New Sectors; Co-evolution of Internal and External Factors of Sectors; Focus on KETs, and Interrelation Between IS Approaches.

CSIS approach intends to examine the transformation of cross-sectoral dynamics and puts focus on convergence and cross-sectoral co-evolution aspects, as they are essential to changes of dynamics of respective IS in the perspective of cross-sectoral transformation, whether there is a formation of new sectors or not.

Furthermore, by exploring demand-side innovation policies, it is observed that there is an interactive push-pull dynamic in convergence. This means that, cross-sectoral approaches based on convergence and demand-side innovation policies lead to the emergence of KETs, while also the emergence of the KETs triggers convergence, and eventually the formation of new sectors, blurred sectoral boundaries, and new sectoral dynamics. As a two-sided and interactive relation, a technology-push dynamic produces radical innovations which can give rise to entirely new markets and societal developments. Market-pull dynamics that led to innovations are formed from the very beginning in response to specific market needs. The impact of KETs, however, raises

the potential of radical innovation in the market such as sharing economy and platform-based/on-demand mobility services.

The aforementioned findings invited a **Cross-Sectoral Innovation System (CSIS)** approach that constitutes of analyzing the interaction of more than one dominant sector. **For the observed need for CSIS approach, both conceptual and analytical studies are conducted. An analysis method is developed and proposed, namely “cross-sectoral matching analysis method”, based on matching sub-technology areas and/or keywords of more than one dominant sector.** For the design of cross-sectoral matching analysis method, firstly, matching method of building blocks of an IS (particularly SIS approach) is determined as four dimensions and thirteen indicators, which are; (1) Matching of Needs (such as legislation, strategies, etc.), (2) Matching of Capacity (such as scientific and technological capacity, etc.), (3) Matching of Strategic Importance (such as the impact of KETs, etc.), and, (4) Matching of Global Trends Analysis (trend of world markets and strategies of dominant actors).

Consecutively, in accordance with the research questions of this thesis, the aforementioned dimensions and indicators are narrowed down for the CSIS approach based on convergence. Cross-sectoral matching analysis method is designed using literature review findings while benefitting from current methods for mapping IS and measuring convergence. Therefore, the main dimensions of the analysis method are determined as technology convergence, cross-sectoral co-evolution, and industry convergence; as they are reviewed in the literature review. However, since it is observed that industry convergence happens as a result of an interactive and iterative push-pull mechanism of all convergence types, and also all convergence types are in close interaction and influence with each other, science convergence and market convergence are considered as organic dimensions of the analysis method.

Descriptive study inputs are used for the selection of automotive and ICT sectors for the case study and “cross-sectoral matching analysis method” is applied for both sectors. Both quantitative (bibliometric analysis via scientific publication and patent

data, global market secondary data of dominant countries and companies of both sectors) and qualitative (expert review via an online structured expert contribution form) methods are applied for measuring cross-sectoral convergence in a co-evolutionary perspective, and observing its reflections over respective IS.

For the quantitative analysis of science convergence, cross-sectoral matching analysis method is applied using sub-technology areas composed of keywords via co-word analysis using retrieved data from the SCOPUS Database. For the quantitative analysis of technology convergence, cross-sectoral matching analysis method is applied using sub-technology areas composed of keywords via co-word analysis using retrieved data from the Derwent Database, only using patent publications. Then, co-occurrence mappings are prepared using VOSviewer. For the quantitative analysis of market convergence, first, cross-sectoral approaches in strategic documents and projects by international organizations are investigated; such as OECD, MGI, JRC-IPTS, McKinsey & Company, DETECON Consulting, CAR Group, SMMT and Frost & Sullivan, Deloitte. Then, cross-sectoral matching analysis based on trends of national RDI strategies, specific landmark projects, national and/or international initiatives, and support mechanisms of dominant countries and companies for automotive and ICT sectors are researched and examined. For the selection of dominant countries and companies, results of quantitative analyses of science and technology convergence are used, as well as RDI performances of countries and companies by global indexes (such as; Global Innovation Index 2017-2018, Global Competitiveness Index 2017-2018, The 2018 Global Innovation 1000).

Ten dominant countries are determined and examined as the following; USA, China, Germany, Japan, UK, South Korea, Canada, France, Singapore, and Taiwan. Accordingly, ten dominant companies are determined and examined, which are; Google LLC (Alphabet Inc.), Microsoft Corporation, Apple Inc., Siemens AG, General Motor Company (GM), Continental AG, Ford Motor Company, Volkswagen Group (VW), Toyota Motor Corporation, and Tesla Inc. Also, Crunchbase Database is used for investigating cross-sectoral investments of the examined companies.

During the research and examination of determined companies, other companies are also observed according to their relations with the examined companies.

The key findings of the case study show how automotive and ICT sectors are transforming in a co-evolutionary way based on technology convergence (mutually affected by science and market convergences) in the process of forming a new sector. Emerging KETs are determined, which either lay the foundations of a new sector (via technology and market convergence) or become the new sector itself (for instance, *EHVs, CAVs, autonomous vehicles, cyber-physical systems, AI-supported automotive embedded software and systems, vehicle software, in-vehicle communication technologies and applications, IoT (internet of vehicles and internet of everything), intelligent/smart mobility, etc.*).

Findings suggest that in the future it is probable that a brand new sector would emerge as AUTO-ICT. Because, especially for the constituents of the sectors (organizational structures, knowledge-base, technology-base, market-base, business models, market formation, interdisciplinary areas, workforce, infrastructures, etc.) a profound shift is observed between these dominant sectors. It is evident that these dominant sectors do not act as related/supportive sectors as the current SIS approach suggests, especially in the presence of disruptive impacts of convergence. Dominant actors of respective dominant sectors, and their knowledge, technology and market-bases are shifting towards distinct dominant sectors.

Moreover, in the dynamics of SIS, a shift from vertical integration to cross-sectoral/horizontal integration is observed as another emerging trend. While putting the focus on the interaction of two dominant sectors, as automotive and ICT, observations regarding other distinct sectors are also obtained, particularly with energy sector (*energy storage and alternative fuels, advanced battery technologies, e-mobility, vehicle-to-grid, integration with smart cities, and smart buildings, etc.*), advanced materials (*light weighted vehicles, advanced battery materials, etc.*), advanced manufacturing (*3D printing, digital twin, integration with Industry 4.0, smart*

manufacturing, etc.) and service sectors (digital business models, sharing economy, business as a service, infrastructure as a service, integration with blockchain, etc.).

On the other hand, while one of the expected results would be that automotive is transforming and co-evolving with the impact of digital transformation; all shifts and convergences as a result of the case study indicate a two-sided co-evolutionary transformation. This means that, both sectors are triggering each other's transformation in terms of all convergence types, but most impactful via technology convergence.

This thesis specifically employs this proposed method in analyzing the convergence trend integrated with IS perspective. A framework of CSIS concept is also proposed as complementary to the current IS approaches. The proposed method, as well as the definition and the framework of CSIS approach, are developed reflecting on the weaknesses stated in the IS literature regarding examination and measurement of dynamic boundaries of sectoral systems. Such as, continuous change of knowledge-base, types of relevant actors; the structure of sectoral system. Moreover, reflecting over the requirement of expansion of the type of sectoral systems and catching up in different sectoral systems in advanced research in SIS approach.

Briefly, CSIS approach as a concept intends to examine the cross-sectoral, interdependent, and co-evolutionary relationships within more than one dominant sector that converge together and can alter similar components in national, sectoral, regional, and even in wider global innovation systems.

CSIS approach can be defined as a framework of cross-sectoral distinct institutions whose interactions contribute jointly to the production and innovation processes of more than one converging dominant sector which may even evolve into a completely new sector.

7.2. Key Policy Implications

In accordance with the key findings of this thesis, three policy implications are presented below. These policy implications are also suggested in relation to the barriers that CSIS approach faces, which are presented in Figure 6.2, in Chapter 6. The aforementioned barriers include; lack of understanding and focus on cross-sectoral approaches, lack of cross-sectoral data for policy makers, lack of adoption of KETs, issues of access to data, lack of funding for multi-, cross-, and interdisciplinary areas, R&D and test infrastructures, lack of skills and capabilities at the systemic and organizational level, lack of cross-sectoral regulations and standardization, and global and national emergencies, etc.

7.2.1. Policy Implication 1: Development of Collaborative Innovation Mechanisms for Cross-Sectoral Approaches

As one of the key findings of the case study, national and international cross-sectoral collaborations, alliances and platforms are impactful for the rapid change of the structures of the actors in the sectors while blurring the boundaries of the sectors. Therefore, the adoption of KETs and access to data are key for the actors of the sectors in transformation, especially while data-centric business models play a huge role in the transformation of sectors and/or the formation of new sectors. This means that, proactive policy measures are needed, that would enable actors of the sectors to benefit from the opportunities for innovation and growth generated through technology convergence, in co-opetition. Examples for cross-sectoral collaborations from the case study can be given as, Microsoft's "Connected Vehicle Platform", which uses its cloud product, Microsoft Azure, that involves global dominant actors of automotive sector; or "Google Open Automotive Cross-Sectoral Alliance", a global partnership of global automakers, aftermarket and technology dominant actors to create connected vehicles. Another example can be given as "Japan Automotive Software Platform and Architecture (JASPAR)", which is established for ensuring reliability by

standardization and common use of electronic control system and in-vehicle network, and involves partnerships from both automotive and ICT global dominant actors.

In those collaborations, not only dominant actors but also niche KET developers are included. On the other hand, direct international cross-sectoral collaborations, rather than partnerships, are also very common. For example, Germany, a dominant country for the AUTO sector, making an international collaboration with Taiwan, a dominant country for the ICT sector, to develop and merge its AUTO sector capacity with ICT sector infrastructure. The aforementioned examples are providing the required collaborative ecosystem and benefits of dominant actors in the cross-sectoral perspective. For example, consortium support mechanisms to support hybrid collaborations where the main sector and sub-sector organizations from different sectors are effective (partnerships between public research institutions, cross-sectoral excellence centers for project development and training programs in multi/cross/interdisciplinary research areas, based on the research needs of the private sector) for the transformation of cross-sectoral dynamics. In that regard, recently developed consortium and RDI value chain integrated support programs in Turkey are considered as positive developments (such as, Ministry of Industry and Technology Tech-Driven Industry Program, TÜBİTAK Call for High-Technology Platforms, and TÜBİTAK SAYEM), which can be improved for supporting cross-sectoral approaches.

Strengthening companies/research institutions for developing converging technologies is also important. KETs are important for the converging technology innovation process and cross-sectoral convergence. In that regard, companies/research institutes need external assistance to get from a stage of being aware of KETs, and their convergence effect, to actually using them actively in an innovation process and for commercial purposes. While fostering access to financial sources, state-of-the-art infrastructures and high-skilled expertise are crucial, developing the collaborative ecosystem should also be supported. In that regard, a matching mechanism can be developed for developing cross-sectoral partnerships, while supporting intermediary

organizations and spaces for cross-sectoral collaboration and co-creation for business & public researchers. Additionally, co-creation comes forward for cross-sectoral collaborations. Because, cross-sectoral approaches involve different actors from more than one dominant sector, as well as end-users as the main actors. Further examples of mechanisms that would foster co-creation and cross-sectoral collaborations can be given as cross-sectoral clusters, networks, platforms, collaborative start-up accelerators, and living labs.

7.2.2. Policy Implication 2: Support for Multi-, Cross- and Interdisciplinary Areas, R&D and Test Infrastructures

In accordance with the Policy Implication 1 given above, another barrier in the cross-sectoral approaches is the lack of funding for multi-, cross-, and interdisciplinary areas, as well as cross-sectoral projects. Multi-, cross-, and interdisciplinary aspects are crucial since the CSIS approach considers the convergence of more than one dominant sector with more than one KET. In that regard, an example from the case study can be given as Fraunhofer Institute's AUTO-ICT cross-sectoral collaboration initiative (AutoMobil Production Collaboration) in Germany, which was launched by eighteen research institutes under Fraunhofer (such as, Production Engineering and Automation, Production Technology and Advanced Materials, Environment, Security and Energy Technologies, etc.). In this initiative, multi-, cross- and interdisciplinary research are supported aiming to produce next-generation vehicles. Another important example can be given as, Canada (ICT-Based) Automobile Excellence Center (Auto21), funded by the Canadian Centers of Excellence Networking Secretariat (NCE), which was established to build an AUTO-based ICT sector and form an AUTO-ICT sector in Canada. Auto21 consists of forty-six universities, two hundred researchers, and one hundred and twenty public-private sector partnerships (PPPs). R&D is carried out in multi-, cross- and interdisciplinary areas in line with private sector needs, and R&D outputs are commercialized in PPPs.

On the other hand, related project calls and technology roadmaps should reflect the cross-sectoral perspective, related KETs, and multi-, cross- and interdisciplinary areas. Especially, KETs that are in process of forming new sectors should be analyzed, and then considered separately for technology roadmapping studies and project calls. From the finding of the case study, in the case of AUTO-ICT sector, CAVs, autonomous vehicles, cyber-physical systems can be given as examples of KETs that are forming new sectors. For instance in Turkey, while the notion of project call plans is changing, they are still generally prepared sectoral-based, even though the call title and the context are cross-sectoral. Cross-sectoral areas mean cross-sectoral, vertical and horizontal integrated organizations. Therefore, for cross-sectoral aspects of the project calls a multi-organizational approach can be adapted.

Moreover, in many countries, including Turkey, there are project calls for sub-technologies for dual-use and cross-sectoral use, but the reflections of these calls and call results (developed R&D and technologies) in other sectors are also very important. The cross-sectoral aspects of the supported areas and produced outputs as a result of the calls should be considered. In that regard, multi-organizational “Cross-Sectoral Concertation Boards” can be established to work on both the dual-use possibilities and commercialization of KETs.

Lastly but importantly, test infrastructures are also crucial in cross-sectoral approaches, especially regarding digital transformation. Many countries are supporting the development of test infrastructures while also strengthening the capacity of interdisciplinary research centers. Examples can be given as, UK Digital Catapult 5G test-bed in Bristol or Centre for Connected and Autonomous Vehicles (C-CAV), which are used for self-driving vehicle tests. In this regard, while there are recent developments and established infrastructures in Turkey, a specific mechanism to support the development of test infrastructures and eliminate access issues, remains open for improvement.

7.2.3. Policy Implication 3: Need for Proactive Cross-Sectoral Regulations and Standardization Process

Another important outcome of the thesis is the critical role of demand-side innovation policies in the case of cross-sectoral approaches affected by technology convergence. For example, in the automotive sector tax incentive reductions, and in the ICT sector the standardization policies can be emphasized. It is observed that technology-push based innovation triggered by standards and standardization processes reflects on the formation of the market and the emergence of new sectors. More importantly, in the case of cross-sectoral approaches dynamics of the dominant sectors reflect on each other's dynamics, which creates a co-evolutionary ecosystem. For example, one of the key findings of the case study showed that not only ICT is transforming the AUTO sector, it is co-evolutionary, and also an AUTO-ICT sector is emerging. Separate markets of the dominant sectors, which are also prior sectors for the examined countries, are converging via the support of upper structure (strategies, policies, institutions, regulations, standards, supports, mission-oriented initiatives, alliances, national/international cross-sectoral collaborations, etc.) and new markets (as well as sectors) are forming, such as EHV (electro-mobility), autonomous and connected vehicles (CAVs), intelligent mobility, etc., which are also fostered by KETs such as AI, ML, big data technologies. As a result, it is expected that sectors will be horizontally integrated in the 2030s in the cross-sectoral context, especially regarding the ICT sector. These changes trigger the requirements of rapid improvement in the dynamics of NIS and SIS, which should be responded by proactive cross-sectoral regulations and standardization for KETs.

Besides, changes in customer demands, regulations and standards can be at least equally important factors, for the transformation of respective NIS and SIS. In the cross-sectoral approaches, regulations require to be based on cross-product, cross-platform, and cross-sectional licensing, etc. Formation of the market is affected by convergence very rapidly that the adequacy and stability of public policy and the legal framework generally lack in catching up. For example, while the examined companies

in the case study are observed to be addressing the challenges of becoming pioneers of the emerging AUTO-ICT sector, they are also designing standardizations for the market formation, therefore creating global competition and proprietary value chain, which should be covered by cross-sectoral proactive regulations.

7.3. Future Studies and Further Remarks

Technology convergence affects the boundaries and the definitions of the sectors and may result in the formation of new sectors based on KETs. This implies that the boundaries of the innovation systems blur as well. Further policy measures should involve methods to analyze cross-sectoral aspects for better understanding the trends for policy makers to develop measures to eliminate the barriers. The most important barrier for the cross-sectoral approaches is that there is a lack of understanding and focus. Cross-sectoral matching analysis method based on sub-technology areas and keywords is an effective tool as introduced in this thesis. Further analyses might involve index studies such as, comparing more than two dominant sectors in one country (national-regional), or comparing developed and developing countries (international) in their context. The proposed analysis method can be also used for the identification of potentials for convergence and innovation systems. So that, implementation of measures for the new innovation system based on convergence, can be examined.

Moreover, the proposed cross-sectoral matching analysis method is expected to be applicable for analyzing more than two dominant sectors. As aforementioned, the findings of the descriptive study and the case study both showed that the foundations of new sectors involve more converging industries, even traditional ones. For example, in the case of automotive and ICT, results are obtained for energy, advanced materials, manufacturing, and service sectors. In the case of analyzing more than two dominant sectors, it is considered that self-defined sectoral specifications and/or coding would be required depending on the related sources and databases. Similar to the method that

was applied for bibliometric analysis of technology convergence based on patents, as applied in this thesis; while considering the path dependency challenge.

Relatedly, another barrier is the lack of cross-sectoral data for policy makers. For example, in the proposed cross-sectoral matching analysis method, both bibliometric data (publications and patents) and secondary data for dominant actors are used, based on sub-technology areas and keyword clusters of automotive and ICT sectors. However, coding and text mining are applied to actually analyze the correct data, to eliminate the technics that are used for the development of data (such as, AI and ML), and to observe cross-sectoral approaches, as there is actually no direct way to retrieve cross-sectoral data by only determining specific sub-technology areas and keywords. Same limitations apply for multi-, cross-, and interdisciplinary areas but in current methods reviewing the multi-, cross-, and interdisciplinary research co-word and co-citation analyses are considered as accurate. Nevertheless, there is no data separation for multi-, and cross-disciplinary areas in the databases and only interdisciplinary data can be retrieved from the related databases that regard to journals in interdisciplinary areas.

Accordingly, improvement of data interfaces is crucial that enables the retrieval of cross-sectoral data directly. While there are no determination and collection of cross-sectoral data by related organizations, one of the direct ways can be to have a way to analyze the citations in a cross-sectoral perspective. For example, while still having limitations, patent data interfaces are providing both forward and backward citation data separately, whereas scientific publication data interfaces provide cited data. In this thesis, backward citations are used for analyzing patent data for the aim of observing cross-sectoral spillovers and co-evolutionary aspects, better. It would be very useful for policy makers to have the same system for scientific publication data interfaces as they only collect forward citation data. Additionally, it would be beneficial to develop techniques for identifying the citing areas (sub-technology areas, KETs) in terms of both scientific publications and patents. It should also be noted that, while developing the method applied in this thesis, techniques such as webometrics

and cross-sectoral investment analyses were also considered among the methods that could be conducted. However, aforementioned methods could be applied in a limited way due to data access issues. Further measures would be very beneficial in integrating and developing innovative techniques, especially for advancing simulation models.

Moreover, firms are also facing similar data challenges and data access barriers. In that case, data access issues create disadvantages in the competitive landscape, especially for domestic manufacturers and SMEs regarding the adoption of KETs, or investment decisions. On the other hand, key findings of the case study demonstrated a challenging competitive landscape for the dominant actors, but also co-opetitive, regarding automotive and ICT cross-sectoral co-evolution perspective. Future studies focusing on the same sectors and/or different sectors and/or different dimensions, such as competition, would reflect more challenging conditions for the actors of the selected sectors; thus more destructive results for the existing sectors, as the evolutionary economics literature would suggest. Accordingly, future studies would also include efforts in improving the applicability of the proposed method and framework of CSIS approach that a policy toolkit for policy makers can be developed.

Lastly, as the conceptualization of the CSIS approach in this thesis suggests, global and/or national emergencies can also emerge as barriers for the cross-sectoral dynamics. In that regard, there is a debate around global/national emergencies (such as pandemics), that how they affected the pace of the technology convergence or the sectors. While the digital transformation is accelerating unpredictably, especially with the pandemic, and its value is multiplying, cross-sectoral approaches should also be examined for policymaking. For instance, an OECD (2020) study shows that the recent crisis because of the pandemic has led to a decrease in demand across sectors, with particularly strong effects on some sectors that widely differ in terms of R&D intensity. Within the service sectors, tourism, travel, and leisure sectors, as well as sectors requiring contact between consumers and service providers (e.g. hairdressers, retailers) were affected by restrictions on movement and social distancing. The impact of these effects on R&D and innovation systems is likely to be minor as the average

company's R&D investment in these sectors is low. However, more R&D-intensive activities were also affected, including manufacturing sectors with long global supply chains (e.g. automotive, electronics) and, subsequently, elsewhere; as well as sectors producing durable and investment products, many of which are R&D-intensive, as demand for such products slows during downturns.

On the other hand, April 2020 data show that, particularly firms in the food tech, digital health, and cybersecurity, received more venture capital funding compared to the 2018/19 averages. There is also different converging demands; such as, large manufacturing firms, some firms in the automotive, aviation, or consumer goods sectors have repurposed part of their production lines to manufacture urgently needed medical equipment, such as ventilators, respirator equipment, masks, etc. Such production adjustments differ in terms of complexity (Betti and Heinzmann, 2020). As can be seen, the converging sectors in transformation are better at engaging in efforts in other sectors in case of emergencies. These types of efforts also created cross-sectoral co-evolutionary aspects in respective IS. Therefore, as emphasized before, introducing flexibilities for current beneficiaries of RDI initiatives, continuous support for dual-use of technologies, multi/cross/interdisciplinary research, and fostering a collaborative and co-creative ecosystem are considered as crucial.

As a result, the key findings of this thesis show that convergence (particularly technology convergence), while having disruptive effects for sectors and IS by transforming the boundaries and dynamics; also presents one of the most fundamental growth opportunities for economies. Additionally, KETs that are mutually created by the effect of the convergence have the power to change the fundamentals of economies, businesses, and IS. The boundaries of sectors are blurring and the notion of "industry" itself is changing, while cross-sectoral knowledge, technology and market-bases are converging. As a result, convergence factors and co-evolutionary aspects of sectors, as well as emerging challenges, are transforming the competitive landscape and innovation systems together.

Therefore, this thesis aimed to propose a method and a framework for a better understanding of the aforementioned cross-sectoral dynamics, and methods to measure how cross-sectoral dynamics change and/or transform, how new sectors form in the presence of disruptive technology convergence trend in the perspective of IS approaches. In conclusion, however developing, while benefiting from current IS approaches, particularly SIS and current analysis methods, works of literature of IS and convergence are integrated, and a cross-sectoral matching analysis method is proposed and applied as a case study for automotive and ICT sectors. Using the key findings, a framework of Cross-Sectoral Innovation System (CSIS) approach is also depicted in complementary of current IS approaches.

REFERENCES

- Agency for Science, Technology and Research (A*STAR). (2015). Retrieved November, 2017, from <https://www.a-star.edu.sg/>
- Allarakhia, M. and Walsh, S. (2012). Analyzing and organizing nanotechnology development: application of the institutional analysis development framework to nanotechnology consortia. *Technovation* 32 (3), 216-226.
- Allevin, M. (2016). Deutsche Telekom, Huawei Among Those Testing LTZ-V for Next-Gen Auto Tech. *FierceWireless*. Retrieved November, 2018, from www.fiercewireless.com/tech/deutsche-telekom-huawei-among-those-testing-ltev-for-next-gen-auto-tech
- Allied Market Research. (2018). Autonomous Vehicle Market Outlook 2026. Retrieved April, 2019, from <https://www.alliedmarketresearch.com/autonomous-vehicle-market>
- Allman, K., Edler, J., Georghiou, L., Jones, B., Miles, I., Omidvar, O., Ramlogan, R. and Rigby, J. (2011). Measuring Wider Framework Conditions for Successful Innovation - A System's Review of UK and International Innovation Data, London. Retrieved December, 2013, from http://www.nesta.org.uk/library/documents/Measuring_Framework_web_v2.pdf
- Amaral, L.A.N. and Ottino, J.M. (2004). Complex Networks: Augmenting the Framework for the Study of Complex Systems. *European Physical Journal B* 38, 147-162.
- Aminullah, E., Fizzanty, T., Indraprahasta G.S., Asmara I.J. (2015). Technological convergence in Indonesian firms: cases of bio-based chemical product innovation. *Asian Journal of Technology Innovation*, 23:sup1, 9-25.
- Apple Car, iMore. (2019a). Project Titan, Retrieved April, 2019, from <https://www.imore.com/apple-car>

Apple Car, Macrumors. (2019b). Apple's vehicle project, focused on building an autonomous driving system. Retrieved April, 2019, from <https://www.macrumors.com/roundup/apple-car/>

Apple CarPlay. (2019). Retrieved April, 2019, from <https://www.apple.com/ios/carplay/>

Apple, iOS CarPlay. (2019). Retrieved April, 2019, from <https://www.apple.com/ios/carplay/available-models/>

ARK Investment Management LLC (ARK). (2018). Tesla through the Lens of Apple. Retrieved November, 2018, from <https://ark-invest.com/research/tesla-through-the-lens-of-apple>

Athreye, S. and Keeble, D. (2000). Technological convergence, globalisation and ownership in the UK computer industry. *Technovation* 20, 227-245.

Auto21. 2013. Canada (ICT-Based) Automobile Excellence Center. Retrieved December, 2013, from <https://auto21.ca/en/subcontent?page=ae2100>

Automotive Industry Association. (2021). Turkish automotive industry in brief (January-March 2021), Retrieved April, 2021, from <http://www.osd.org.tr/homepage>

Baranger, M. (2001). Chaos, complexity, and entropy: A physics talk for non-physicists. *Wesleyan University Physics Dept. Colloquium*, Retrieved December, 2013, from <http://necsi.org/projects/baranger/cce.pdf>

Barnatt, C. (2016). The New Industrial Convergence. Retrieved April, 2018, from <https://www.explainingthefuture.com/nic.html>

Beiker, S., Hansson, F., Suneson, A. and Uhl, M. (2016). How the convergence of automotive and tech will create a new ecosystem, *McKinsey & Company*, Retrieved November, 2018, from <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-the-convergence-of-automotive-and-tech-will-create-a-new-ecosystem>

- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., and Rickne, A. (2005). Analyzing the dynamics and functionality of sectoral innovation systems – a manual, report delivered to VINNOVA, (30 March 2005). *A revised version of this report was presented at the DRUID Tenth Anniversary Summer Conference 2005, June 25-27, Copenhagen.*
- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., and Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy* (2008), Volume 37, Issue 3, 407-429.
- Betti, F. and Heinzmann, T. (2020). From perfume to hand sanitiser, TVs to face masks: how companies are changing track to fight COVID-19. *WEF*. Retrieved May, 2020, from <https://www.weforum.org/agenda/2020/03/from-perfume-to-hand-sanitiser-tvs-to-face-masks-how-companies-are-changing-track-to-fight-covid-19/>
- Bezzina, J. and Sanchez, B. (2005). Technological convergence and regulation. Challenges facing developing countries. *WSIS 2005, Communications & Strategies Special Issue by Info Dev*. Retrieved November, 2018, from https://www.cto.int/wp-content/themes/solid/_layout/dc/k-r/Communication_and_Strategies.pdf
- Bigliardi, B., Dormio, A.I., Galati, F. (2012). The adoption of open innovation within the telecommunication industry. *European Journal of Innovation Management*, Vol. 15 Iss: 1, 27-54.
- Blakenberg, A. and Buenstorf, G. (2016). Regional co-evolution of firm population, innovation and public research? Evidence from the West German Laser industry. *Research Policy* 45 (2016), 857-868.
- Blind, K. (2009). Standardisation: A Catalyst for Innovation, *Inaugural Address, Rotterdam School of Management, Erasmus University, Rotterdam.*
- Blok, H.J. (2000). On the nature of the stock market: simulation and experiments. *Doctoral Thesis, Department of Physics and Astronomy, University of British Columbia.*

- BMW. (2017). BMW Connected Drive. Retrieved November, 2018, from www.bmw.com/com/en/newvehicles/7series/sedan/2015/showroom/services_and_apps.html
- Borés, C., Saurina, C., Torres, R. (2003). Technological convergence: a strategic perspective. *Technovation* 23, 1-13.
- Bornkessel, S, Bröring, S. and Omta, S.W.F. (2016). Cross-industry Collaborations in the Convergence Area of Functional Foods. *International Food and Agribusiness Management Review Volume 19 Issue 2*, 2016.
- Bresnahan, T., and Malerba, F. (1999). Industrial dynamics and the evolution of firms and nations competitive capabilities in the world computer industry, in Mowery D. and Nelson R. (Eds), *The Sources of Industrial Leadership*, Cambridge University Press, Cambridge.
- Bröring, S. (2005). The front end of innovation in converging industries: The case of Nutraceuticals and functional foods. *DUV, Wiesbaden, Germany*. Retrieved April, 2019, from <https://www.springer.com/gp/book/9783835000742>
- Bröring, S., Cloutier, L.M., Leker, J. (2006). The front end of innovation in an era of industry convergence: evidence from nutraceuticals and functional foods. *R&D Manage.* 36(5), 487-498.
- Burrus, D. (2013). Convergence: A Power Tool for Innovation, Retrieved May, 2014, from <http://www.burrus.com/2013/08/convergence-a-power-tool-for-innovation/>
- Callon, M., Law, J., & Rip, A. (Eds.). (1986). Mapping the dynamics of science and technology: Sociology of science in the real world. *London: Real World, MacMillan, London, UK*.
- Camiña, S.L. (2010). A Comparison of Taxonomy Generation Techniques Using Bibliometric Methods: Applied to Research Strategy Formulation, *Composite Information Systems Laboratory (CISL) Sloan School of Management, Room E53-320 Massachusetts Institute of Technology Cambridge, MA 02142*, 15-18.

Canada, Moving Forward in Science, Technology and Innovation. (2014). Retrieved February, 2014, from https://www.ic.gc.ca/eic/site/113.nsf/eng/h_07658.html

CAR Group (Center for Automotive Research). (2017). Roadmap for Automotive Technology Advancement, Retrieved November, 2018, from <http://www.cargroup.org/roadmap-for-automotive-technology-advancement/>

CATAllience. (2010). Germany International Automobile and ICT Cross-Sectoral Innovation Challenge, Retrieved February, 2014, from http://www.cata.ca/Media_and_Events/Press_Releases/cata_pr09201002.html

CB Insights. (2019). 40+ Corporations Working on Autonomous Vehicles, Retrieved March, 2020, from <https://www.cbinsights.com/research/autonomous-driverless-vehicles-corporations-list/>

Chang, Y.-C. and Chen, M.-H. (2004). Comparing approaches to systems of innovation: the knowledge perspective, *Technology in Society* 26 (2004), 17–37.

Chavey, W. (2013). How Google Hopes to Disrupt the Auto Industry, Retrieved November, 2013, from <http://beta.fool.com/willchavey/2013/08/19/how-google-hopes-to-disrupt-the-auto-industry/42226/>

CNRS. (2017). Nanocar Race. Retrieved August, 2019, from <https://www.cnrs.fr/en/worlds-first-international-race-molecule-cars-nanocar-race>

Continental Mag. (2019). Continental Automotive. Retrieved March, 2020, from <https://mag.continental.com/en/interview-with-dr-dirk-abendroth/>

Cooke, P., Heidenreich, M., Braczyk, H.-J. (Eds.). (2004). Regional Innovation Systems: The Role of Governance in a Globalized World. *Second ed. Routledge, London.*

Cooke, P. (2012). Complex Adaptive Innovation Systems: Relatedness and Transversality in the Evolving Region (Regions and Cities). *JASSS.*

Counterpoint Research. (2018). Global Connected Car Tracker 2018 Report. Retrieved April, 2019, from <https://www.counterpointresearch.com/125-million-connected-cars-shipments-2022-5g-cars-2020/>

Counterpoint Research. (2019). Global Smartphone Share. Retrieved April, 2019, from <https://www.counterpointresearch.com/global-smartphone-share/>

Calusen, T.H. (2013). Firm heterogeneity within industries: how important is 'industry' to innovation?. *Technology Analysis and Strategic Management Journal*, Volume 25, 2013, Retrieved April, 2020, from <https://www.tandfonline.com/doi/abs/10.1080/09537325.2013.785512>

CPC. (2020a). Connected Places Catapult. Retrieved June, 2020, from <https://cp.catapult.org.uk/about-us/>

CPC. (2020b). Intelligent Mobility Accelerator. Retrieved June, 2020, from <https://cp.catapult.org.uk/2020/03/05/intelligent-mobility-accelerator-accepting-applications-for-next-cohort/>

Crunchbase. (2020a). Google Acquisitions. Retrieved March, 2020, from <https://www.crunchbase.com/search/acquisitions/e7ce74aed0c0705bf5a4ce28eaae202e>

Crunchbase. (2020b). Waymo Acquisitions. Retrieved March, 2020, from <https://www.crunchbase.com/search/acquisitions/03b7b5f670e66fde5106eb97a4eb82b1>

Crunchbase. (2020c). Apple Acquisitions. Retrieved March, 2020, from <https://www.crunchbase.com/search/acquisitions/af9fa639e86cfd4a68ef03b353bd4bf2>

Crunchbase. (2020d). Siemens Acquisitions. Retrieved March, 2020, from https://www.crunchbase.com/search/acquisitions/field/organizations/num_acquisitions/siemens

Crunchbase. (2020e). Ford Smart Mobility. Retrieved March, 2020, from https://www.crunchbase.com/search/acquisitions/field/organizations/num_acquisitions/ford-smart-mobility

Crunchbase. (2020f). Tesla Motors Acquisitions. Retrieved March, 2020, from https://www.crunchbase.com/organization/tesla-motors/acquisitions/acquisitions_list#section-acquisitions

Crunchbase. (2020g). WirelessCar. Retrieved March, 2020, from <https://www.crunchbase.com/organization/wirelesscar>

Curran, C.S., Bröring, S., Leker, J. (2010). Anticipating converging industries using publicly available data. *Technol. Forecast. Soc. Change* 77 (3), 385–395.

Curran, C.S. and Leker, J. (2011). Patent indicators for monitoring convergence – examples from NFF and ICT, *Technol. Forecast. Soc.* 78 (2), 256–273.

Curran, C.S. (2013). The Anticipation of Converging Industries A Concept Applied to Nutraceuticals and Functional Foods. *Springer-Verlag London* 2013.

DARPA. (2004). The DARPA Grand Challenge: Autonomous Robotic Ground Vehicles (2004 and 2014). Retrieved November, 2017, from <https://www.darpa.mil/news-events/2014-03-13>

Dawid, H. and Wersching, K. (2006). On Technological Specialization in Industrial Clusters: An Agent-based Analysis. *Handbook of Research on Nature Inspired Computing for Economy and Management. Rennard JP, Vol.2, 2006*, 367–378.

Deloitte. (2014). Industry 4.0 Challenges and Solutions for the Digital Transformation and Use of Exponential Technologies. Retrieved November, 2018, from <https://www2.deloitte.com/ch/en/pages/manufacturing/articles/manufacturing-study-industry-4.html>

Deloitte. (2017). The Future of the Automotive Value Chain, 2025 and beyond. Retrieved November, 2018, from <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/consumer-business/us-auto-the-future-of-the-automotive-value-chain.pdf>

DETECON Consulting. (2011). Think 2032! Position for ICT everywhere, *Deutsche Telekom Group, January 2011*.

Dosi, G. and Nelson, R.R. (2010). Technical change and industrial dynamics as evolutionary processes. *Handbook Economy of Innovation*, 1, 51–127.

Edler, J. (2007). Demand-based innovation policy. *Manchester Business School Working Paper*, 529.

Edler, J., Georghiou, L., Uyarra, E. and Blind, K. (2009). Monitoring and Evaluation Methodology for the EU Lead Market Initiative: A Concept Development. *University of Manchester/Fraunhofer ISI, Technical University, Berlin*.

Edquist, C. (1997). Systems of Innovation; Technologies, Institutions and Organizations. *Science, Technology and the International Political Economy Series*.

Enkel, E., Gassmann, O. and Chesbrough, H. (2009). Open R&D and open innovation: exploring the phenomenon. *R&D Management* 39 (4), 311–316.

Enkel E., and Gassmann, O. (2010). Creative imitation: exploring the case of cross-industry innovation. *R&D Management* 40(3), 256–271.

Ernst & Young. (2016). The upside of disruption: Megatrends shaping 2016 and beyond. Retrieved June, 2020, from https://www.ey.com/en_gl/megatrends

Ernst & Young. (2018). What's after, what's next? The upside of disruption: Megatrends shaping 2018 and beyond. Retrieved June, 2020, from https://www.ey.com/en_gl/megatrends

Ernst & Young. (2020). Are you reframing your future or is the future reframing you? Megatrends 2020 and beyond. *EYQ 3rd edition*, Retrieved June, 2020, from https://www.ey.com/en_gl/megatrends

EUROSTAT. (2007a). NACE Revision 2.0, Methodologies and Working Papers, Retrieved April, 2019, from

<https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF>

EUROSTAT. (2007b). EUROSTAT High-Tech Classification of Manufacturing Industries based on NACE Rev.2. *Lastly modified in 2018*. Retrieved April, 2019, from https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:High-tech_classification_of_manufacturing_industries

Fai, F., and von Tunzelmann, N. (2001). Industry-specific competencies and converging technological systems: Evidence from patents. *Structural Change and Economic Dynamics*, 12(2), 141–170.

FORD Company. (2011). Fact Sheet: Ford SYNC Voice-Controlled Communications and Connectivity System. *Ford Motor Company*. Retrieved November, 2013, from http://media.ford.com/article_display.cfm?article_id=33358

FORD Company. (2019a). Autonomous 2021. Retrieved March, 2020, from <https://corporate.ford.com/articles/products/autonomous-2021.html>

FORD Company. (2019b). Driving innovation in Silicon Valley. Retrieved March, 2020, from <https://corporate.ford.com/careers/silicon-valley.html>

FORD OTOSAN. (2021). Turkey Overview. Retrieved April, 2021, from <https://www.fordotosan.com.tr/en/operations/randd/overview>

France Europe 2020. (2013). A Strategic Agenda for Research, Technology Transfer and Innovation, May 2013. Retrieved May, 2014, from https://www.assemblee-nationale.fr/14/cr-oecst/4574_synthesis.pdf

Fraunhofer. (2014). Germany - Fraunhofer AutoMOBILE Production Alliance. Retrieved January, 2014, from (1) <http://www.fraunhofer.de/en/institutes-research-establishments/groups-alliances/automobile-production.html>, (2) <http://www.automobil.fraunhofer.de/assets/doc/Allianz-Automobil-KB-technologies-for-automobile-production.pdf>

Freeman, C. (1974). The Economics of Industrial Innovation, *Harmondsworth: Penguin Books*.

Freeman, C. (1987). *Technology Policy and Economic Performance: Lessons from Japan*, Pinter: London.

Furukawa T., Mori, K., Arino, K., Hayashi, K. and Shirakawa, N. (2015). Identifying the evolutionary process of emerging technologies: A chronological network analysis of World Wide Web conference sessions. *Technological Forecasting & Social Change* 91 (2015), 280–294.

Gao, P., Kaas, H-W., Mohr, D. and Wee, D. (2016). Disruptive trends that will transform the auto industry. *McKinsey&Company Report*. Retrieved November, 2018, from <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry>

Galindo-Rueda, F. and Verger, F. (2016). OECD Taxonomy of Economic Activities Based on R&D Intensity. *OECD Science, Technology and Industry Working Papers*, 2016/04, OECD Publishing, Paris. <http://dx.doi.org/10.1787/5jlv73sqqp8r-en>

Gambardella, A. and Torrisir, S. (1998). Does technological convergence imply convergence in markets? Evidence from the electronics industry, *Research Policy* 27 (1998), 445–463.

Gartner. (2014). Industry Convergence -The Digital Industrial Revolution. Retrieved December, 2014, from <https://www.gartner.com/en/documents/2684516/industry-convergence-the-digital-industrial-revolution>

Gassmann, O., Enkel, E., and Chesbrough, H. (2010). The future of open innovation. *R&D Management* 40(3), 213–221.

Gassmann, O., Daiber, M. and Enkel, E. (2011). The role of intermediaries in cross-industry innovation processes. *R&D Management* 41(5), 457–470.

General Motors (GM). (2011). OnStar Helps Your Phone Tell Your Car Where to Go. Retrieved November, 2013, from http://media.gm.com/content/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2011/Aug/0829_onstar

- General Motors (GM). (2018). General Motors, Meet the People Bringing Your Digital Life into Your Car. Retrieved November, 2018, from <https://www.gm.com/our-stories/technology/amazon-alexa-engineering-technology.html>
- General Motors (GM). (2019). Path to Autonomous. Retrieved April, 2019, from <https://www.gm.com/commitments/path-to-autonomous.html>
- Georghiou, L. (2007). Demanding Innovation. Lead Markets, Public Procurement and Innovation. *A NESTA Publication, London*.
- Germany, BMBF. (2010). The High-Tech Strategy 2020. Retrieved November, 2017, from <https://www.bmbf.de/en/the-new-high-tech-strategy-2322.html>
- Germany, BMBF. (2017). The High-Tech Strategy 2025. Retrieved April, 2019, from https://www.bmbf.de/upload_filestore/pub/Research_and_innovation_that_benefit_the_people.pdf
- Germany's China Strategy 2015-2020. (2015). Strategic Framework for Cooperation with China in Research, Science and Education, *Federal Ministry of Education and Research*. Retrieved November, 2017, from https://www.research-in-germany.org/dam/jcr:4ab5394d-5c62-4f5c-90bd-0f6b07e9127b/China_Strategy_Longversion.pdf
- Geroski, P.A. (1990). Procurement policy as a tool of industrial policy. *International Review of Applied Economics*, Vol. 4 (2), 182–198.
- Gerum, E., Sjurts I. and Stieglitz N. (2004). Industry Convergence and the Transformation of the Mobile Communications System of Innovation.
- Geum, Y., Kim, C., Lee, S., and Kim, M. (2012). Technological convergence of IT and BT: Evidence from patent analysis. *ETRI Journal*, 34(3), 439–449.
- Geum, Y. (2016). How industrial convergence happens: A taxonomical approach based on empirical evidences. *Technological Forecasting & Social Change* 107 (2016), 112–120.

Google Open Automotive Alliance. (2014). Retrieved January, 2014 and April, 2019, from <http://www.openautoalliance.net/>

Google. (2017). Self-driving Car. Retrieved November, 2018, from <https://www.google.com/selfdrivingcar>

Global Market Insights. (2019). In-Car Apps Market Size. *Industry Analysis Report, Regional Outlook, Application Development, Price Trend, Competitive Market Share & Forecast, 2021 – 2027*. Retrieved April, 2019, from <https://www.gminsights.com/industry-analysis/in-car-apps-market>

Grove, N., and Baumann, O. (2008). Technological convergence and open innovation in the mobile telecommunication industry. *Asian J. Technol. Innov.* 16 (1), 45–62.

Hacklin, F. (2008). Management of convergence in innovation—Strategies and capabilities for value creation beyond Blurring Industry boundaries. *Physica-Verlag, Heidelberg, Germany*.

Hacklin, F., Marxt, C., Fahrni, F. (2009). Coevolutionary cycles of convergence: an extrapolation from the ICT industry. *Journal of Technological Forecasting and Social Change*, 76, 23–736.

Hacklin, F., and Wallin, M.W. (2013). Convergence and interdisciplinarity in innovation management: a review, critique, and future directions. *Serv. Ind. J.* 33, 774–788.

Hammerschmidt, C. (2016). “Audi vehicles get their own IoT identity”, EE Times, Retrieved from: www.automotive-eetimes.com/news/audi-vehicles-get-their-own-iot-identity [Nov, 2018]

Han, J., Chung, S., and Sohn, Y. (2009). Technology convergence: When do consumers prefer converged products to dedicated products?. *Journal of Marketing*, 73, 97–108.

Harvard Business Review. (2012). Chapter 2, The Twelve Themes of the New Economy Retrieved December, 2013, from <http://www.businessweek.com/chapter/tapch02.htm>

HERE Company. (2017). Sensor Ingestion. Retrieved November, 2013, from <https://company.here.com/automotive/new-innovations/sensor-ingestion>

Hood, W., and Wilson, C. (2001). The literature of bibliometrics, scientometrics, and informetrics. *Scientometrics* 52 (2), 291–314. <https://doi.org/10.1023/A:1017919924342>

IBM. (2016). Redefining Boundaries Insights from the Global C-suite Study. *IBM Institute for Business Value*, 4–7.

iMore. (2019). Apple Car?. Retrieved April, 2019, from <https://www.imore.com/apple-car>, <https://www.macrumors.com/roundup/apple-car/>

Invest in Turkey. (2021). Automotive Sector. Retrieved April, 2021, from <https://www.invest.gov.tr/en/sectors/pages/automotive.aspx>

ITRI. (2013). Taiwan-Germany Automotive-ICT Cross-Sectoral Collaboration Platform. Retrieved December, 2013, from https://www.itri.org.tw/eng/econtent/about/about09_02.aspx?SCid=1&sid=100

Jambit. (2018). Project: RACE – New system architecture for vehicles. Retrieved November, 2018, from <https://www.jambit.com/en/competences/innovation-stories/siemens-race/>

Jang, Y. (2009). Technological convergence through industrial research collaboration: a comparative analysis between the U.S. and Korea. *Asian Journal of Technology Innovation*, 17(1), 101–120.

Japan Industry News. (2016). Japan's Society 5.0: Going Beyond Industry 4.0. Retrieved November, 2017, from <https://www.japanindustrynews.com/2017/08/japans-society-5-0-going-beyond-industry-4-0/>

JASPAR. (2018). Japan Automotive Software Platform and Architecture. Retrieved August, 2019, from <https://www.jaspar.jp/en>

- Jeong, S. (2014). Strategic collaboration of R&D entities for technology convergence: exploring organizational differences within the triple helix. *Journal of Management & Organization*, 20(2), 227–249.
- Jeong, S. and Lee, S. (2015). What drives technology convergence? Exploring the influence of technological and resource allocation contexts. *Journal of Engineering and Technology Management* 36 (2015) 78-96, 1–17.
- Jeong, S, Kim, J-C, and Choi, J.Y. (2015). Technology convergence: What developmental stage are we in?. *Scientometrics*, 104, 841–871.
- JRC-IPTS. (2010). Is Europe in The Driver's Seat? The Competitiveness of the European Automotive Embedded Systems Industry Report, 2010. EC. Retrieved November, 2017, from <https://ec.europa.eu/jrc/en/news/ict-innovation-automotive-industry-key-competence-europe-8300>
- Kaas, H.-W., Mohr, D., and Gao, P. (2016). Automotive revolution - perspective towards 2030. *McKinsey & Company - Advanced Industries*. Retrieved April, 2019, from <https://doi.org/10.1365/s40112-016-1117-8>.
- Kang B. and Oh D. (2012). The Emerging Trend of Technological Convergence and Tasks for Science Parks. *WTR* (2012);1, 16–26.
- Kaiser, R. and Kripp, M. (2010). Demand-Orientation in National Systems of Innovation: A Critical Review of Current European Innovation Policy Concepts. *Summer Conference 2010 on "Opening Up Innovation: Strategy, Organization and Technology"*, Imperial College London Business School, June 16 - 18, 2010.
- Karvonen, M., Lehtovaara, M., and Kässi, T. (2012). Build-up of understanding of technological convergence: Evidence from printed intelligence industry. *International Journal of Innovation and Technology Management*, 9(03), 1250020-1–1250020-24.
- Karvonen, M. and Kässi, T. (2013). Patent citations as a tool for analysing the early stages of convergence. *Technol. Forecast. Soc.* 80, 1094–1107.

- Katz, J.S. (2006). Indicators for complex innovation systems. *Research Policy* 35 (2006), 893–909.
- Katz, J.S. (2016). What Is a Complex Innovation System?. *PLOS ONE, Public Library of Science*, vol. 11(6), 1–24.
- Kern, J. and Wolff, P. (2019). The digital transformation of the automotive supply chain– an empirical analysis with evidence from Germany and China: Case study contribution to the OECD TIP Digital and Open Innovation Project.
- Kilian, R., Gauger, C. Stein, J., and Sherrer, M. (2017). Connected Vehicles and the Road to Revenue. *The Boston Consulting Group (BCG) Report*, Retrieved August, 2019, from https://image-src.bcg.com/Images/BCG-Connected-Vehicles-and-the-Road-to-Revenue-Dec-2017_tcm9-179631.pdf
- Kim, M. and Kim, C. (2012). On A Patent Analysis Method for Technological Convergence. *Procedia - Social and Behavioral Sciences* 40 (2012), 657–663.
- Kim, N., Lee, H., Kim, W., Lee, H., Suh, J.H. (2015). Dynamic patterns of industry convergence: Evidence from a large amount of unstructured data. *Research Policy* 44, 1734–1748.
- KPMG. (2014). Future State 2030: The global megatrends shaping governments. *KPMG International*.
- KT and Netmania. (2015). Korean big 3, getting ready for 5G SK Telecom, KT and LG U+ (1): KT. *Net Trend Conference, Illustrated by Netmania*, Retrieved April, 2019, from <https://www.netmanias.com/en/post/blog/7108/5g-gigabit-internet-iot-kt-korea-lte-lte-a/korean-big-3-getting-ready-for-5g-sk-telecom-kt-and-lg-u-1-kt>
- Lee, T. L., and von Tunzelmann, N. (2005). A dynamic analytic approach to national innovation systems: The IC industry in Taiwan. *Research Policy*, 34(4), 425–440.
- Lee, W.S. (2015). Predicting the pattern of technology convergence using big-data technology on large-scale triadic patents. *Technological Forecasting & Social Change*, 317–329.

- Lee, W.S., Han, E.J., Sohn S.Y. (2015). Predicting the pattern of technology convergence using big-data technology on large-scale triadic patents. *Technological Forecasting & Social Change* 100 (2015), 317–329.
- Leydesdorff, L. (2007). Mapping interdisciplinarity at the interfaces between the Science Citation Index and the Social Science Citation Index. *Scientometrics*, 71, 391–405.
- Li, Y., Li, Y., Zhao, Y., Wang, F. (2013). Which factor dominates the industry evolution? A synergy analysis based on China's Information and Communications Technology (ICT) industry. *Article in Engineering Economics*, March 2014. doi: 10.5755/j01.ee.25.3.5823 .
- Lundvall, B.-A. (Ed). (1992). National Systems of Innovation and Interactive Learning. New York: Pinter Publishers, London.
- Lundvall, B.-A. (2005). National Innovation Systems - Analytical Concept and Development Tool. *DRUID 2005*.
- Made in China 2025 (MIC2025). (2015). Retrieved November, 2017, from <http://english.www.gov.cn/2016special/madeinchina2025>
- Malerba, F. and Orsenigo, L. (1997). Technological Regimes and Sectoral Patterns of Innovative Activities. *Industrial and Corporate Change*, 1997, vol. 6, issue 1, 83–117.
- Malerba, F. (1999). Sectoral Systems of Innovation and Production. *DRUID Conference on: NISs, Industrial Dynamics and Innovation Policy*.
- Malerba, F. (2002a). Sectoral Systems of Innovation and Production. *Research Policy*, 31, 247–264.
- Malerba, F. (2002b). New challenges for sectoral systems of innovation in Europe. *Paper to be presented at the DRUID Summer Conference 2002 on Industrial Dynamics of the New and Old Economy - who is embracing whom?*, 2001, Copenhagen, Denmark.

- Malerba, F. (2004). Sectoral System of Innovation Basic Concepts in Malerba F. (Ed) (2004). *Sectoral System of Innovation: Concepts Issues and Analyses Six Major Sector in Europe*, Cambridge Univ. Press, UK, 12–14.
- Malerba, F. (2005). Innovation and the evolution of industries. *Journal of Evolutionary Economics*, Springer, Vol. 16(1), 3–23.
- Malerba, F., Nelson, R.R., Orsenigo, L. and Winter, S. (2007). Demand, innovation, and the dynamics of market structure: The role of experimental users and diverse preferences. *Journal of Evolutionary Economics*, Springer, Vol. 17(4), 371–399.
- Malerba, F. and Mani, S. (2009). Sectoral systems of innovation and production in developing countries: an introduction. *Chapters, in: Franco Malerba & Sunil Mani (Ed), Sectoral Systems of Innovation and Production in Developing Countries, chapter 1*, Edward Elgar Publishing. 3–156.
- Malerba, F. and Adams, P. (2014). Sectoral Systems of Innovation. *Dodgson, M. and Phillips, N. The Oxford Handbook of Innovation Management*, Oxford University Press, 2014, 196–199.
- Marr, B. (2018). The Amazing Ways Tesla Is Using Artificial Intelligence and Big Data. *Article in Forbes*. Retrieved November, 2018, from <https://www.forbes.com/sites/bernardmarr/2018/01/08/the-amazing-ways-tesla-is-using-artificial-intelligence-and-big-data/#2ffad2a42704>
- Martin, M.J.C. (1994). *Managing Innovation and Entrepreneurship in Technology-based Firms*. Wiley-IEEE.
- McCracken, L. (2012). Digital Commerce Convergence... a New Creed of Leader Needed. Retrieved April, 2019, from <https://lauramccracken.wordpress.com/tag/convergence/>
- McKinsey Global Institute (MGI). (2013). Disruptive technologies: Advances that will transform life, business, and the global economy. Full Report (May 2013). Retrieved October, 2013, from http://www.mckinsey.com/~media/McKinsey/dotcom/Insights%20and%20pubs/MGI/Research/Technology%20and%20Innovation/Disruptive%20technologies/MGI_Disruptive_technologies_Full_report_May2013.ashx

- McKinsey&Company. (2016). Automotive revolution – perspective towards 2030, How the convergence of disruptive technology-driven trends could transform the auto industry. Retrieved November, 2018, from <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry>
- Metcalf, S. (1998). *Evolutionary Economics and Creative Destruction*. Routledge & Kegan Paul, London.
- Microsoft. (2018). Microsoft and the automotive industry: A year in review. Retrieved August, 2019, from https://www.linkedin.com/pulse/microsoft-automotive-industry-year-review-sanjay-ravi?articleId=6482082224903720960#comments-6482082224903720960&trk=public_profile_post
- Ministry of Economic Affairs (MoEA), R.O.C. (2017). Technology and Innovation Driven Industrial Development Policy. Retrieved November, 2017, from https://www.moea.gov.tw/Mns/english/content/Content.aspx?menu_id=1743
- Ministry of Industry and Technology of Turkey. (2019). Turkey's 2023 Industry and Technology Strategy (Turkish). Retrieved June, 2020, from <https://www.sanayi.gov.tr/assets/pdf/SanayiStratejiBelgesi2023.pdf>
- Ministry of Transport and Infrastructure of Turkey. (2019). National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan. Retrieved June, 2020, from <https://www.uab.gov.tr/uploads/announcements/ulusal-akilli-ulasim-sistemleri-strateji-belgesi-v/ulusal-akilli-ulas-im-sistemleri-strateji-belgesi-ve-2020-2023-eylem-planı-eng.pdf>
- Morillo, F., Bordons, M., and Gómez, I. (2003). Interdisciplinarity in science: a tentative typology of disciplines and research areas. *J. Am. Soc. Inf. Sci. Technol.* 54 (13), 1237–1249.
- Mowery, D.C. and Rosenberg, N. (1979). The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies. *Research Policy*, Vol. 8, No. 2, 102–153.
- Mowery, D.C. and Nelson, R.R., (Eds). (1999). Sources of Industrial Leadership: Studies of Seven Industries. New York, Cambridge University Press.

- Muller, J. (2013). Will Google Kill The Auto Industry? No, and Here's Why. Retrieved December, 2013, from <http://www.forbes.com/sites/joannmuller/2013/01/25/will-google-kill-the-auto-industry/>
- Mui, C. (2013). Google's Trillion-Dollar Driverless Car - Part 2: The Ripple Effects. *Article in Forbes*. Retrieved December, 2013, from <http://www.forbes.com/sites/chunkamui/2013/01/24/googles-trillion-dollar-driverless-car-part-2-the-ripple-effects>
- Murmann, J.P. (2003). Knowledge and Competitive Advantage. *Cambridge University Press, Cambridge*.
- Murmann, J.P. (2013a). The coevolution of industries and important features of their environments. *Organiz. Sci.* 24, 58–78.
- Murmann, J.P. (2013b). The co-development of industrial sectors and academic disciplines. *Sci. Public Policy* 40, 229–246.
- NACE Coder. (2019). Central Statistics Office Database, data.cso.ie. Retrieved April, 2019, from <https://www.cso.ie/px/u/NACECoder/Index.asp>
- Nanoindustries. (2019). Retrieved April, 2019, from <http://nanoindustries.com/>
- Nanotechnology Market Outlook 2025. (2019). Report in Allied Market Research. Retrieved from: <https://www.alliedmarketresearch.com/nanotechnology-market>
- NATO. (2020). Science & Technology Trends 2020-2040, Exploring the S&T Edge. *NATO Science & Technology Organization*, 23–26. Retrieved June, 2020, from https://www.nato.int/nato_static_fl2014/assets/pdf/2020/4/pdf/190422-ST_Tech_Trends_Report_2020-2040.pdf
- Nelson, R.R. (Ed). (1993). National Innovation Systems - A Comparative Analysis. *Oxford University Press, New York, NY*.

- Nelson, R.R. (1994). The co-evolution of technology, industrial structure, and supporting institutions. *Industrial and Corporate Change* 3, 47–63.
- Nemet, G.F. (2009). Demand pull, technology push, and government-led incentives for non-incremental technical change. *Research Policy*, Vol. 38, Issue 5, June, 700–709.
- Netmarketshare. (2019). Operating System Global Market Share. Retrieved January, 2014 and August, 2019, from <http://www.netmarketshare.com/operating-system-market-share.aspx?qprid=10&qpcustomd=0>
- Noyons, E.C.M., and Van Raan, A.F.J. (1998). Monitoring scientific developments from a dynamic perspective: Self-organized structuring to map neural network research. *Journal of the American Society for Information Science*, 49(1), 68–81.
- OECD. (2010). Information Technology Outlook 2010. *OECD Publishing, Paris*. https://dx.doi.org/10.1787/it_outlook-2010-en
- OECD. (2011). Demand-side Innovation Policies. *OECD Publishing, Paris*. <https://doi.org/10.1787/9789264098886-en>
- OECD. (2012). Internet Economy Outlook 2012. *OECD Publishing, Paris*.
- OECD. (2014a). Challenges and Opportunities for Innovation through Technology: The Convergence of Technologies. *DSTI/STP(2013)15/FINAL*.
- OECD. (2014b). Nanotechnology In The Context Of Technology Convergence. *Working Party on Nanotechnology Document, DSTI/STP/NANO(2013)10/FINAL, September 2014, Paris*. Retrieved April, 2019.
- OECD. (2015). Digital Economy Outlook 2015. *OECD Publishing, Paris*.
- OECD. (2016). Science, Technology and Innovation Outlook 2016. *OECD Publishing, Paris*.

- OECD. (2017a). Digital Economy Outlook 2017. *OECD Publishing, Paris*. <http://dx.doi.org/10.1787/9789264276284-en>
- OECD. (2017b). The Next Production Revolution: Implications for Governments and Business. *OECD Publishing, Paris*. <http://dx.doi.org/10.1787/9789264271036-en>
- OECD. (2018). Science, Technology and Innovation Outlook 2018. *OECD Publishing, Paris*.
- OECD. (2019). Digital Innovation: Seizing Policy Opportunities. *OECD Publishing, Paris*. Retrieved April, 2019, from <https://doi.org/10.1787/a298dc87-en>
- OECD. (2020). Science, technology and innovation in times of Covid-19 and policy responses. Background Report. Retrieved June, 2020, from https://www.researchgate.net/publication/342082616_Science_technology_and_innovation_in_times_of_Covid-19_and_policy_responses_Preliminary_overview_in_June_2020
- OTEP. (2021). Working Groups. Automotive Technology Platform of Turkey (Otomotiv Teknoloji Platformu). Retrieved April, 2021, from <http://www.otepp.org.tr/Home/CalismaGruplari?dil=EN>
- Pagani, M. (2003). Multimedia and interactive digital TV: Managing the opportunities created by digital convergence. *Pennsylvania: IRM Press*.
- Palmer, C. (1999). Structures and strategies of interdisciplinary science. *Journal of the American Society for Information Science*, 50, 242–253.
- Papadakis, S. (2009). Technological convergence: Opportunities and Challenges. 2–3.
- Pavlinek, P. (2017). Dependent Growth: Foreign Investment and the Development of the Automotive Industry in the East-Central Europe, The State and The Development of the Automotive Industry. *Springer International Publishing*, 2017, 210.

- Pennings, J. M., and Puranam, P. (2001). Market convergence & firm strategy: New directions for theory and research. In *ECIS conference, the future of innovation studies*, Eindhoven, Netherlands.
- Pietrobelli, C. and Gorgoni, S. (2010). Networks, knowledge flows and innovation in the Chilean meat sector. *Int. J. Business Environment*, Vol. 3, No. 2, 160.
- Porter, M. (1990). *The Competitive Advantage of Nations*. New York, Free Press.
- Porter, A. L., Cohen, A. S., Roessner, J. D., and Perreault, M. (2007). Measuring researcher interdisciplinarity. *Scientometrics*, 72(1), 117–147.
- Porter, A. L., and Rafols, I. (2009). Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics*, 81(3), 719–745. doi:10.1007/s11192-008-2197-2.
- Preschitschek, N., Niemann, H., Moehrl, M., Leker, J. (2012). Semantic analyses vs. IPC co-classification analyses of patents: which one better serves to anticipate converging industries?. In: *Proceedings of PICMET 2012*, 566–578.
- Qing, S. (2013). Microsoft launches first auto industry innovation center in China. Retrieved December, 2013, from http://news.xinhuanet.com/english/china/2013-12/19/c_132981228.htm
- R&D Management Conference. (2016), *Session Description by Dr Mihail Roco, Senior Advisor for Science and Engineering in U.S. NSF*. Retrieved May, 2016, from <http://www.rnd2016.eng.cam.ac.uk/sessiondescriptions/session33>
- Research, Innovation and Enterprise Plan 2020 (RIE2020). (2015). Singapore R&D Strategy. Retrieved November, 2017, from <https://www.nrf.gov.sg/rie2020>
- Rifkin, J. (2014). The zero marginal cost society: The internet of things, the collaborative commons, and the eclipse of capitalism. *St. Martin's Press*.
- Roco, M.C. and Bainbridge, W.S. (2002). Converging Technologies for Improving Human Performance. *National Science Foundation, Arlington, VA*.

Rosenberg, N. (1976). Perspectives on Technology. *Cambridge Univ. Press, Cambridge, UK.*

Ryan, V. (2013). Technology push vs Market Pull. Retrieved November, 2013, from <http://www.technologystudent.com/prddes1/revcardtec1.html>

Saraçoğlu, D. (2014). Determining Cross-Sectoral Trends From The Perspective Of Demand Side Policies and Sectoral Innovation Systems Literature: Assessment of Information and Communication Technologies and Automotive Cross-Sectoral Approach. *TÜBİTAK Expertise Thesis (Turkish, TÜBİTAK Internal Document).*

SBB. (2019). Eleventh Development Plan (2019-2023). *Presidency of the Republic of Turkey Presidency of Strategy and Budget (TC Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı).* Retrieved June, 2020, from https://www.sbb.gov.tr/wp-content/uploads/2020/06/Eleventh_Development_Plan-2019-2023.pdf

Schummer, J. (2004). Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology. *Scientometrics*, 59, 425–465.

Scientific Publications (2020). What is the difference between Web of Science and Scopus?. Retrieved June, 2021, from <https://ru.publ.science/en/blog/v-chem-rznitsa-mezhdu-web-of-science-i-scopus>

Sharp, P.A. (2011). Convergence is a new paradigm that can yield critical advances in a broad array of sectors, from health care to energy, food, climate, and water. *MIT Washington Office*, 4–9.

Siemens. (2012a). RACE: Robust and Reliant Automotive Computing Environment for Future eCars. Retrieved December, 2013 and November, 2018, from http://www.siemens.com/innovation/en/news/2012/e_inno_1207_1.htm

Siemens. (2012b). Software Car, 2012. Retrieved December, 2013 and November, 2018, from http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall2012/_html_en/automotive-software.html

Siemens. (2018). Automotive Manufacturing, Siemens Digital Twins and e-Car. Retrieved November, 2018, from <https://new.siemens.com/global/en/markets/automotive-manufacturing/e-car.html>

Soete, L., Verspagen, B., ter Weel, B. (2010). Systems of innovation, In: Bronwyn, Hall, Rosenberg, Nathan (Eds.), *Handbook of the Economics of Innovation*. Elsevier, Amsterdam, 1160–1180.

Small, H. (1977). A co-citation model of a scientific specialty: A longitudinal study of collagen research. *Social Studies of Science*, 7, 139–166.

SSIR. (2018). The Need for Cross-Sector Collaboration. Retrieved December, 2018, from https://ssir.org/articles/entry/the_need_for_cross_sector_collaboration#

Statcounter Database. (2019). Search Engine Market Share. Retrieved April, 2019, from <http://gs.statcounter.com/search-engine-market-share>

Startcounter Database. (2019). OS Market Share. Retrieved April, 2019, from <http://gs.statcounter.com/os-market-share>

STIP. (2021). TÜBİTAK, Centers of Excellence Program, 2019. OECD-STIP. Retrieved April, 2019, from <https://stip.oecd.org/stip/policy-initiatives/2019%2Fdata%2FpolicyInitiatives%2F26241>

Tesla. (2018). Tesla, Apple of Cars, on the verge of its golden age. Article in CleanTechnica. Retrieved April, 2019, from <https://cleantechnica.com/2018/11/10/tesla-apple-of-cars-on-verge-of-its-golden-age/>

Tesla Inc. (2018). Company Information. Retrieved November, 2018, from <https://www.tesla.com/>

TOGG. (2019). Press Release 2019. Retrieved April, 2021, from <https://www.togg.com.tr/Dosyalar/Pdf/togg-journeytoinnovation-press-release-eng-27122019.pdf>

TÜBİTAK SAYEM. (2021). TÜBİTAK National Support Programmes: Industrial Innovation Networks. Retrieved April, 2021, from <https://tubitak.gov.tr/en/funds/industry/national-support-programmes/content-sayem-industrial-innovation-networks>

The 13th Five Year Basic Plan of China 2016-2020. (2016). *National Development and Reform Commission*. Retrieved November, 2017, from https://en.ndrc.gov.cn/newsrelease_8232/201612/P020191101481868235378.pdf

The Society of Motor Manufacturers and Traders (SMMT). (2017). Retrieved April, 2019, from <https://www.smmt.co.uk/wp-content/uploads/sites/2/UK-Automotive-Priorities-Securing-the-Strength-of-the-UK-Automotive-Industry-2017-2022-v2.pdf>

The Society of Motor Manufacturers and Traders (SMMT). (2019). Connected and Autonomous Vehicles: Winning the Global Race to Market Report. Retrieved August, 2019, from <https://www.smmt.co.uk/reports/connected-and-autonomous-vehicles-the-global-race-to-market/>

The UK Catapult Centers Network. (2018). Retrieved August, 2019, from <https://catapult.org.uk/>

The UK Industrial Strategy. (2018). Retrieved August, 2019, from <https://www.gov.uk/government/topical-events/the-uks-industrial-strategy>

The UK Industrial Strategy Automotive Sector Deal. (2018). Retrieved August, 2019, from <https://www.gov.uk/government/publications/automotive-sector-deal>

The US White House. (2015). Strategy for American Innovation, October 2015. Retrieved November, 2017, from https://obamawhitehouse.archives.gov/sites/default/files/strategy_for_american_innovation_october_2015.pdf

The US White House. (2019a). Research and Development Priorities for American Leadership in Wireless Communications. Retrieved May, 2019, from <https://www.whitehouse.gov/wp-content/uploads/2019/05/Research-and-Development-Priorities-for-American-Leadership-in-Wireless-Communications-Report-May-2019.pdf>

The US White House. (2019b). Artificial Intelligence for the American People. Retrieved June, 2019, from <https://www.whitehouse.gov/ai/>

Tijssen, R.J.W. (1992). A quantitative assessment of interdisciplinary structures in science and technology: Co-classification analysis of energy research. *Research Policy*, 21(1), 27–44.

Tipan, E. (2016). SENSORIS to fast-track development of self-driving cars. Article in Autoindustriya. Retrieved November, 2018, from www.autoindustriya.com/auto-industry-news/sensoris-to-fast-track-development-of-self-driving-cars.html

TOYOTA. (2013). Smart Mobility Society – Next Generation Telematics. Toyota Global Innovation. Retrieved December, 2013, from http://www.toyota-global.com/innovation/smart_mobility_society/next_generation_telematics/

TOYOTA. (2017). Toyota and NTT ICT Platform Collaboration for R&D of Connected Cars. Toyota Global. Retrieved November, 2018, from <https://global.toyota/en/detail/15917538>

USA National Nanotechnology Initiative. (2019). Nanotechnology Benefits. Retrieved April, 2019, from <https://www.nano.gov/you/nanotechnology-benefits>

Vault. (2019). Industries: Nanotechnology. Retrieved April, 2019, from <https://www.vault.com/industries-professions/industries/nanotechnology>

van Eck, N. J., and Waltman, L. (2014). Visualizing bibliometric networks. In: Ding Y., Rousseau R., Wolfram D. (Eds) *Measuring Scholarly Impact*. Springer, Cham. https://doi.org/10.1007/978-3-319-10377-8_13.

von Hippel, E. (2005). Democratizing Innovation. *The MIT Press, Cambridge, MA*.

Volkswagen. (2013). Fully Intelligent, Connected Cars Volkswagen's Vision of the Future. ITU. Retrieved December, 2013, from http://www.itu.int/dms_pub/itu-t/oth/06/1B/T061B0000020056PDFE.pdf

- Volkswagen. (2018). Volkswagen Digital Transformation Gathers Speed. *Volkswagen Press Releases*. Retrieved April, 2019, from <https://www.volkswagen-newsroom.com/en/press-releases/volkswagens-digital-transformation-gathers-speed-4115>
- Waring, J. (2016). Intel CEO: 5G crucial to manage coming M2M data flood. *Mobile World Live*. Retrieved April, 2019, from <https://www.mobileworldlive.com/asia/asia-news/intel-ceo-says-coming-m2m-data-flood-requires-5g>
- Waymo. (2019). Waymo Journey. Retrieved April, 2019, from <https://waymo.com/journey/>
- Wilkinson, J. M. (2005). Future Areas of Technological Convergence. In: Kang B. and Oh D., 2012, *The Emerging Trend of Technological Convergence and Tasks for Science Parks*, WTR (2012);1, 16–26.
- Wirtz, B.W. (2001). Reconfiguration of value chains in converging media and communications markets. *Long Range Plan.* 34 (4) (2001), 489–506.
- Yuming, G., Xiaoman, L., Libo, T., and Darrell, M.W. (2017). Smart transportation in China and the United States. *China Academy of Information and Communication Technology (CAICT)*.
- Zach, E. (2013). Apple's strategy to take over the automotive sector: Apple iOS in the car. *BGR Apple iOS in Car Market Share*. Retrieved December, 2013, from <http://bgr.com/2013/11/06/apple-ios-in-car-market-share/>
- Zang, M.Z. (2014). Innovation Management in China. *The Oxford Handbook of Innovation Management*, 355–375.
- Ziegler, B. (2009). Methods for Bibliometric Analysis of Research: Renewable Energy Case Study. *Composite Information Systems Laboratory (CISL), MIT*.
- Zitt, M., Ramanana-Rahary, S., and Bassecoulard, E. (2005). Relativity of citation performance and excellence measures: From cross-field to cross-scale effects of field-normalisation. *Scientometrics*, 63, 373–401.

APPENDICES

A. SCOPE OF SUB-TECHNOLOGY AREAS AND KEYWORD CLUSTERS FOR AUTOMOTIVE AND ICT SECTORS

Table A.1. Automotive Sub-Technology Areas and Scopes

Automotive TAs (6)	Keyword Cluster Scope
Automotive-Battery Technologies	Infrastructure technologies and charging ecosystem technologies for EHV; Battery materials, packaging, cooling systems, recycling systems (Less volume / higher energy density / fast charging / recyclable/hybrid batteries; new generation AGM, VRLA, start / stop batteries); Energy Management Systems; Hydrogen and fuel cells; Auxiliary energy storage and packaging systems (ultracapacitor and related system studies).
Electric and Hybrid Vehicle (EHV) Technologies	Design and design verification studies for EHV technologies; Electric motor, control and drive technologies; Energy management systems / software and system integrations in EHV.
Automotive - Material Technologies	Advanced material technologies (plastic, rubber, steel sheet etc.) for innovative products; Material and hardware technologies to improve crash performance; Materials technologies for lightening (engineering plastics and metal technologies - thin-section steel sheet on vehicle and component basis; use of magnesium, titanium, composite and nano materials, etc.).
Engine&Powertrain Technologies	Design and design verification studies of internal combustion engines; Vehicle dynamics, power, power transmission systems control equipment; Design and design verification studies for drivetrain.
Automotive-Embedded Systems	Security and Safety Focused Technologies: Vehicle/driver information technologies; V2X Communication, Information systems; Infrastructure interaction systems equipped with advanced technology.
Innovative Vehicle Design and Design Verification	Modification of existing vehicle designs; Vehicle interior trim-seat, coating, etc., vehicle exterior trim-rim, wiper, mirrors, auxiliary mechanical/ electrical elements, engine cooling elements, etc.

Table A.2. ICT Sub-Technology Areas and Scopes

ICT TAs (14)	Keyword Cluster Scope
Information Security (including Cybersecurity and Cryptology)	Developing new generation crypto algorithms and new generation security methods; Common encryption technologies, development of encrypted communication (voice&video) technologies; Cryptology chips/devices/software, cryptology-related software development; Data privacy and security; Privacy preserving data management; Security in e-government apps; Finance apps, payment systems; Program analysis tools to catch vulnerability in software; Biometric recognition systems, technologies; Security applications for smart systems; Location privacy in geographic apps; Authentication technologies; Satellite communication security; Development of security methods in parallel with developments in cloud computing; Information security for smart cards; Video encryption; Cybersecurity systems; Internet security; E-signature apps&standardization; Cloud security; Detection and prevention of malicious software; Development of domestic security products (firewall, etc.); Safe and fast access data storage techniques; Secure network architectures.

Table A.2. (Cont'd)

Cloud Computing (including Virtualization and Supercomputing)	Transporting sectoral softwares to cloud servers; Developing cloud services (SCM, ERP, CRM, etc.); Energy efficiency for services and software in the cloud, “Green computing”; Data centers and providing energy saving services with data centers; Intercloud interoperability; Hosting technologies and apps; Cloud-based sectoral software (automotive, education, health, tourism, agriculture, livestock and food); Data management and analytics; High performance computing; Parallel computing (programming); Quantum computing; Virtual server management; Security, privacy, networking of cloud servers network loads.
Digital Content and Internet Technologies	E-Government; E-Commerce; E-Learning Technologies; Semantic Web Technologies; Web 2.0 Technologies; Digital Library; Multimedia Technologies; E-Business.
Display Technologies	LED, OLED, AMOLED; Thin film transistor (TFT) Circuit Array; Organic-inorganic semiconductor materials (Polymer, Small molecule, organometallic and inorganic nanoparticles); Innovative electrode materials; Substrate materials; Ultra thin glass; Low Power LED Chip; Medium Power LED Chip; LED Chip Cooling Technologies; Photoluminescent Materials; Flexible subbase/anode electrode; Space-permeable sheet material; Light-emitting polymer; Electron-permeable sheet material; Electron transfer sheet material, Organic electronic devices (OPV, OLED, OFET, etc.), Roll to roll and sputtering systems; Cluster or in-line (PVD/CVD vacuum evaporation) production line.
Photonics	Photonics; Nanophotonics; Quantum photonics; Ultrafast optics; Optics communications; Fiber tech; Photodetectors; Semiconductor laser; Solid state laser; Plasmonics; Photonic crystal; Emitting diode; Integrated optics; Optoelectronics; Quantum electronic device.
Broadband Technologies (including Wired/Wireless Communication Technologies, IP Technologies, Telecom Equipment and Services)	Fiber infrastructure and usability; Fiber technologies; Development of technologies that enable the use of flexible spectrum; development of technologies that will use spectrum efficiently; Using software-based radio technologies; development of base station compatible with wireless broadband technologies (such as 3G, 4G), 3G, 4G, 5G technologies and beyond, Future Internet LTE-Advanced and post-LTE systems; New generation internet technologies; Ultra high capacity optics supporting networks; HD video distribution, 8x4k high resolution image transmission technologies, video distribution applications; Developing IP Radiolink for use in wireless broadband networks created using only IP technologies; Packet routing with software over switches, effective packet management; Satellite broadband single technologies; Data compression technologies; SIP, VOIP; Audio and video codecs; IPv6; Video sharing; Virtual networks; Software Defined Network (SDN); Wireless sensor networks; Systems capable of wireless power transmission; Internet 2; Mobile offload; Wireless self-organizing networks; Intelligent traffic distribution in wireless networks; WBAN (body area) networks), WPAN.
Embedded Systems	Embedded system architecture; Embedded software; Embedded hardware; Embedded communication; Embedded chip; Embedded chip multiprocessor; Network-on-chip; Firmware; Embedded sensors.
Power Electronics	Technologies for sustainable transport systems; Power electronic technologies for EVs, systems that generate electricity from solar or wind energy; Energy management; Development of components; Development of DC-DC converter with high power/volume ratio; providing high efficiency regardless of the power drawn; Development of high performance, small size EMI / EMC filters; Electronic switches that can operate at high voltages, high currents and high temperatures gain great importance in increasing efficiency in systems that generate or use energy.
Micro/Nano/Opto-Electronic Technologies (MEMS, NEMS, MOEMS)	MEMS Accelerometer; MEMS Inertial Measurement Unit (IMU); MEMS based precision clock; RF MEMS switches and capacitors; MEMS circuit components; Reshaped antennas and antenna arrays, receiver/ transmitter to be produced as monolithic (monolithic); Zero level packaging and reliability; Biosensors produced using integrated micro/nano manufacturing techniques; Chemical sensors produced using integrated micro/nano manufacturing techniques; Integrated micro/physical sensors produced using nano manufacturing techniques; Microfluidic-based on-chip-laboratory measurement and analysis systems; microbolometer type uncooled infrared detector array; cost-effective infrared detector arrays using MEMS and CMOS technologies; Chip-level ceramics suitable for microbolometer type uncooled infrared detector arrays or in-vacuum packs using metal bags; High performance detector material (e.g. VOx, VWO, graphene, etc.) or new infrared detection methods, performance enhancer for use in infrared detector arrays developed using MEMS technologies nanophotonic (plasmonic, metamaterial, etc.) structures; multi-band imaging sensor technologies; MEMS devices that can generate energy; Supercapacitors and micro batteries; Micro and microbial fuel cells; Energy harvesting microsystems; Wireless sensor systems that can generate their own energy; System-on-chip.
Semiconductor Technologies and Integrated Circuits	Oscillator; Digital-controlled/Voltage-controlled oscillator; Impulse/Insulator/Acoustic/Integrated circuit testing; Active inductors; Single electron devices/memory/transistors; Gyration; Hetero-nanocrystal memory; Operational amplifier; Analog/RLC circuit; Component technology; Semiconductor manufacturing; Electronic component; Capacitor, System-on-chip; Bipolar/BiCMOS integrated circuit; Superconducting coil.

Table A.2. (Cont'd)

Mobile Communication Technologies (Including IoT and M2M)	Development of mobile communication devices using Software Defined Radio Technologies (SDR); Base station and fem to cell production with the help of SDR; Development of new waveforms to work on software-based mobile communication devices; Software-based Developing common hardware architecture using wireless structures; Data management applications; Compression and transmission technologies; Smartphones/apps; Cognitive radio technologies; Unmixable communication-frequency hopping digital radios; Automatic roaming and non-cellular wireless communication system; Wireless sensor networks; Navigation devices (NFC); 4G, 5G; Converged communication technologies; NFC-M2M; Micro-cell technologies; Near field communication systems; Virtualization in mobile systems; Cognitive radio/ secondary (opportunistic) band access; Optical radio systems (OWC); MAC layer design in networks consisting of heterogeneous base stations; Service quality-based resource sharing in heterogeneous cell sizes; Technologies for network optimization between layers.
Robotics and Mechatronics System Technologies	Robotics and Mechatronics; Micro/nano/swarm robots; Biomimetics; Autonomous agents; Artificial Intelligence; Machine Learning; Autonomous decision-making systems; Computer Vision; Pattern recognition and analysis; Modeling and Simulation Technologies; Human-Computer Interaction.
Software Technologies (Including Mobile Apps, Open Source Software, Animation&Game Technologies)	Software development technologies; Open Source Software; Linux based operating systems; Open source for networking; Open source database systems and database management system; Developing a local database and security applications; Developing open source software for the cloud; Development of important middleware software systems with open source software; Developing software on these platforms by creating common software based infrastructures (developing waveforms on mobile terminals, application development); Business intelligence, work flow software; Database Management and Geographic Information System Solutions; Open source development models; Creating and developing an open source software stack to serve as a service over the cloud.
Data Processing, Storage and Protection Technologies	Image and Video Processing; Signal processing; Speech analysis and processing; Computer Graphics; Database Systems; Data infrastructures; Data mining and data warehousing; Computer Vision and Pattern Recognition.

B. CODING SAMPLES FOR BIBLIOMETRIC ANALYSES

For retrieving scientific publication data, SCOPUS Database is used. In the coding titles, abstracts and keywords are used (TITLE-ABS-KEY). For the proximity operator “W/proximity” is used to boost the score of documents if they contain expressions near each other. For the purpose of narrowing the scope to relevant areas. Table B.1 below, shows the coding sample for AUTO + (ICT_TA1) Information Security (including Cybersecurity and Cryptology).

Table B.1. Coding Sample for AUTO + Information Security Keyword Cluster for Scientific Publication Data Retrieval from SCOPUS Database

TITLE-ABS-KEY ("battery control unit*" w/10 "electric vehicle*") OR TITLE-ABS-KEY("battery control unit*" w/10 "automo*") OR TITLE-ABS-KEY(" Battery control system*" w/10 "automo*") OR TITLE-ABS-KEY(" Battery control system*" w/50 "electric vehicle*") OR TITLE-ABS-KEY(" Battery Management System*" w/10 "automo*") OR TITLE-ABS-KEY(" Battery Management System*" w/10 "electric vehicle*") OR TITLE-ABS-KEY(" Charger" w/10 "automo*") OR TITLE-ABS-KEY(" Charger" w/10 "electric vehicle*") OR TITLE-ABS-KEY("battery module" W/5 "cooling system" w/10 "automo*") OR TITLE-ABS-KEY("battery module" W/5 "cooling system" w/10 "electric vehicle") OR TITLE-ABS-KEY(Battery w/2 "thermal management" w/10 "automo*") OR TITLE-ABS-KEY(Battery w/2 "thermal management" w/10 "electric vehicle*") OR TITLE-ABS-KEY("cooling" w/5 battery w/10 automo*) OR TITLE-ABS-KEY("cooling" w/5 battery w/10 "electric vehicle*") OR TITLE-ABS-KEY("high voltage battery" w/10 "automo*") OR TITLE-ABS-KEY("high voltage battery" w/10 "electric vehicle*") OR TITLE-ABS-KEY(" Hybrid batter*" w/10 "automo*") OR TITLE-ABS-KEY(" Hybrid batter*" w/10 "electric vehicle*") OR TITLE-ABS-KEY("battery packaging system*" w/10 "automo*") OR TITLE-ABS-KEY("battery packaging system*" w/10 "electric vehicle*") OR TITLE-ABS-KEY("battery management system*" w/10 "automo*") OR TITLE-ABS-KEY("battery management system*" w/10 "electric vehicle*") OR TITLE-ABS-KEY("improved flooded battery") OR TITLE-ABS-KEY("enhanced flooded battery") OR TITLE-ABS-KEY("AGM" w/3 battery) OR TITLE-ABS-KEY("EFB" w/3 battery) OR TITLE-ABS-KEY("Absorbent Glass Mat") OR TITLE-ABS-KEY("VRLA" w/10 automo*) OR TITLE-ABS-KEY(" VRLA" w/10 vehicle) OR TITLE-ABS-KEY("valve regulated lead acid" w/10 automo*) OR TITLE-ABS-KEY("valve regulated lead acid" w/10 vehicle) OR TITLE-ABS-KEY(" start / stop batter*") OR TITLE-ABS-KEY(" Lithium-ion module*" w/10 automo*) OR TITLE-ABS-KEY(" Lithium-ion module*" w/10 vehicle) OR TITLE-ABS-KEY(" Energy Management System*" w/10 "automo*") OR TITLE-ABS-KEY(" Energy Management System*" w/10 "electric vehicle*") OR TITLE-ABS-KEY(" Power converter" w/5 automo*) OR TITLE-ABS-KEY(" Power converter" w/5 vehicle) OR TITLE-ABS-KEY(" Power inverter" w/5 automo*) OR TITLE-ABS-KEY(" Power inverter" w/5 vehicle) OR TITLE-ABS-KEY(" DC / DC" w/5 "automo*") OR TITLE-ABS-KEY(" DC / DC" w/5 "electric vehicle*") OR TITLE-ABS-KEY(" ultracapacitor*" w/10 "automo*") OR TITLE-ABS-KEY(" ultracapacitor*" w/50 "electric vehicle*") OR TITLE-ABS-KEY(" supercapacitor" w/50 "automo*") OR TITLE-ABS-KEY(" supercapacitor" w/50 "electric vehicle*") OR TITLE-ABS-KEY("Bidirectional DC-DC supercapacitor Converter*") OR TITLE-ABS-KEY("Embedded System* for Bidirectional DC-DC supercapacitor Converter*") OR TITLE-ABS-KEY(" Electrical energy storage system*") OR TITLE-ABS-KEY(" advanced power electronics applications") OR TITLE-ABS-KEY("electromagnetic interference" w/50 "electric vehicle*") OR TITLE-ABS-KEY("electromagnetic interference" w/50 "automo*") OR TITLE-ABS-KEY(" integrated motor inverter concept*") OR TITLE-ABS-KEY(" Charging System*" w/50 "electric vehicle*") OR TITLE-ABS-KEY(" Charging System*" w/50 "automo*") OR TITLE-ABS-KEY(" fast charging" w/50 "electric vehicle*") OR TITLE-ABS-KEY(" fast charging" w/50 "automo*") OR TITLE-ABS-KEY(" energy management algorithm*") OR TITLE-ABS-KEY(" intelligent network system*" w/50 "automo*") OR TITLE-ABS-KEY("smart grid system*" w/50 "automo*") OR TITLE-ABS-KEY("smart grid system*" w/50 "electric vehicle*") OR TITLE-ABS-KEY(" Smart charging system*") OR TITLE-ABS-KEY(" fuel / power management and transferring") OR TITLE-ABS-KEY("Hybrid vehicle*") OR TITLE-ABS-KEY("Electric Vehicle*") OR TITLE-ABS-KEY("Hybrid vehicle* Technolog*") OR TITLE-ABS-KEY("Electric Vehicle Technolog*") OR TITLE-ABS-KEY("Hybrid electric vehicle* Technolog*") OR TITLE-ABS-KEY("Electric motor drive") OR TITLE-ABS-KEY("Power Management and Transfer bodies") OR TITLE-ABS-KEY("Electric Vehicle" w/5 "Control Unit") OR TITLE-ABS-KEY("Electronic Control Unit*" w/50 "electric vehicle") OR TITLE-ABS-KEY("Electronic Control software" w/50 "electric vehicle*") OR TITLE-ABS-KEY("Power Electronics" w/50 "electric vehicle") OR TITLE-ABS-KEY("Control Electronic*" w/50 "electric vehicle*") OR TITLE-ABS-KEY("Electrically driven auxiliary system*") OR TITLE-ABS-KEY("brake system*" w/50 "electric vehicle*") OR TITLE-ABS-KEY("Electric power steering" w/50 "electric vehicle*") OR TITLE-ABS-KEY("Range extending System*" w/50 "electric vehicle*")

Table B.1. (Cont'd)

OR TITLE-ABS-KEY("Power Converter*" w/50 "electric vehicle") OR TITLE-ABS-KEY("Energy Management System*" w/50 "electric vehicle") OR TITLE-ABS-KEY("Energy Management software*" w/50 "electric vehicle") OR TITLE-ABS-KEY("new generation high-strength steel*") OR TITLE-ABS-KEY(" Advanced High Strength Steel") OR TITLE-ABS-KEY(" Light metals") OR TITLE-ABS-KEY(" Light metal alloys") OR TITLE-ABS-KEY(" Aluminum" w/50 "auto*") OR TITLE-ABS-KEY(" Magnesium" w/50 "auto*") OR TITLE-ABS-KEY(" Titanium" w/50 "auto*") OR TITLE-ABS-KEY(" Composite materials" w/50 "auto*") OR TITLE-ABS-KEY(" Polymer-based composite materials" w/50 "auto*") OR TITLE-ABS-KEY(" Hybrid composite Materials" w/50 "auto*") OR TITLE-ABS-KEY("Sandwich Composite Materials" w/50 "auto*") OR TITLE-ABS-KEY(" Steel forming" w/50 "auto*") OR TITLE-ABS-KEY("metal forming" w/50 "auto*") OR TITLE-ABS-KEY("Workability Method*" w/50 "auto*") OR TITLE-ABS-KEY("Aggregation Method*" w/50 "auto*") OR TITLE-ABS-KEY(" Press- Hardening" w/50 "auto*") OR TITLE-ABS-KEY(" isothermal Forming" w/50 "auto*") OR TITLE-ABS-KEY(" Non- isothermal Forming" w/50 "auto*") OR TITLE-ABS-KEY(" Roll - Forming" w/50 "auto*") OR TITLE-ABS-KEY(" Hot forming" w/50 "auto*") OR TITLE-ABS-KEY("Warm forming" w/50 "auto*") OR TITLE-ABS-KEY(" Tailor blank" w/50 "auto*") OR TITLE-ABS-KEY("Fiber" w/50 "auto*") OR TITLE-ABS-KEY(" Compatibilizer of fiber matrix interface") OR TITLE-ABS-KEY(" Polymer Matrix" w/50 "auto*") OR TITLE-ABS-KEY(" Thermoset based prepreg*") OR TITLE-ABS-KEY(" Thermoset based preform*") OR TITLE-ABS-KEY("thermoplastic based prepreg*") OR TITLE-ABS-KEY("thermoplastic based preform*") OR TITLE-ABS-KEY("Crash performance" w/50 "auto*") OR TITLE-ABS-KEY("internal-combustion engine") OR TITLE-ABS-KEY(" internal combustion engine control unit") OR TITLE-ABS-KEY(" combustion engine powertrain") OR TITLE-ABS-KEY(" the internal combustion engine drive*") OR TITLE-ABS-KEY(" Embedded System* for Motor Drive*") OR TITLE-ABS-KEY(" Powertrain Control Unit") OR TITLE-ABS-KEY(" High power capacity of output*") OR TITLE-ABS-KEY(" syringes" w/50 "auto*") OR TITLE-ABS-KEY(" plugs" w/50 "auto*") OR TITLE-ABS-KEY(" plugs" w/50 "auto*") OR TITLE-ABS-KEY(" electric heaters" w/50 "auto*") OR TITLE-ABS-KEY(" Central Vehicle Control Unit") OR TITLE-ABS-KEY("Safety Oriented Technolog*") OR TITLE-ABS-KEY("Security Oriented Technolog*") OR TITLE-ABS-KEY(" Advanced in-vehicle safety application*") OR TITLE-ABS-KEY(" Advanced driver assistance system*" w/50 "auto*") OR TITLE-ABS-KEY(" Tipping blocking system") OR TITLE-ABS-KEY(" Night driv* support system") OR TITLE-ABS-KEY(" Distance protection warning system") OR TITLE-ABS-KEY(" Emergency brake system") OR TITLE-ABS-KEY(" collision warning system" w/50 "auto*") OR TITLE-ABS-KEY(" Automated parking system") OR TITLE-ABS-KEY(" driver inform* technolog*") OR TITLE-ABS-KEY(" active safety" w/50 "auto*") OR TITLE-ABS-KEY(" passive safety" w/50 "auto*") OR TITLE-ABS-KEY(" Autonomous driv*" w/50 "vehicle*") OR TITLE-ABS-KEY(" Autonomous driv*" w/50 "auto*") OR TITLE-ABS-KEY(" Autonomous control*" w/50 "auto*") OR TITLE-ABS-KEY(" Autonomous control*" w/50 "vehicle*") OR TITLE-ABS-KEY(" Automated Guided Vehicle*") OR TITLE-ABS-KEY(" collision plan* algorithm*") OR TITLE-ABS-KEY("route plan* algorithm*") OR TITLE-ABS-KEY(" V2X Product*" w/50 "Traffic Safety Application*") OR TITLE-ABS-KEY(" V2X Technolog*" w/50 "Traffic Safety Application*") OR TITLE-ABS-KEY(" V2X Products and Technologies Towards Value-Added Service Applications") OR TITLE-ABS-KEY(" Value Added Services" w/50 "auto*") OR TITLE-ABS-KEY(" Value Added Services" w/50 "vehicle*") OR TITLE-ABS-KEY(" V2X Simulator Software") OR TITLE-ABS-KEY(" Human Machine interaction Component*") OR TITLE-ABS-KEY(" Head-up Display system*") OR TITLE-ABS-KEY(" HUD" w/50 "auto*") OR TITLE-ABS-KEY(" HUD" w/50 "vehicle*") OR TITLE-ABS-KEY(" V2X Communication") OR TITLE-ABS-KEY(" Informing system*" w/50 "auto*") OR TITLE-ABS-KEY(" Car- vehicle") OR TITLE-ABS-KEY("vehicle-infrastructure interactive communication provider algorithm*") OR TITLE-ABS-KEY(" Aerial information system*" w/50 "auto*") OR TITLE-ABS-KEY(" navigation" w/50 "auto*") OR TITLE-ABS-KEY(" vehicle communication system*" w/50 "auto*") OR TITLE-ABS-KEY(" Vehicle inform* System*") OR TITLE-ABS-KEY(" Vehicle Entertainment System*") OR TITLE-ABS-KEY("infotainment" w/50 "auto*") OR TITLE-ABS-KEY("infotainment" w/50 "vehicle*") OR TITLE-ABS-KEY(" Vehicle electrical equipment") OR TITLE-ABS-KEY("embedded system*" w/50 "auto*") OR TITLE-ABS-KEY("Vehicle design" w/50 "auto*") OR TITLE-ABS-KEY("Vehicle design" w/50 "electric vehicle*") OR TITLE-ABS-KEY("Vehicle design" w/50 "car*") OR TITLE-ABS-KEY(" electronic component* design") OR TITLE-ABS-KEY("mechatronic component* design") OR TITLE-ABS-KEY(" electronic component* development") OR TITLE-ABS-KEY("mechatronic component* development") OR TITLE-ABS-KEY(" vehicle interior trim") OR TITLE-ABS-KEY(" vehicle exterior trim") OR TITLE-ABS-KEY("car design") OR TITLE-ABS-KEY("automotive design") OR TITLE-ABS-KEY("automobile design") AND TITLE-ABS-KEY("information security") OR TITLE-ABS-KEY("cybersecurity") OR TITLE-ABS-KEY("network security") OR TITLE-ABS-KEY("cryptology") OR TITLE-ABS-KEY("cryptography") OR TITLE-ABS-KEY("cryptanalysis") OR TITLE-ABS-KEY("cryptographic protocol") OR TITLE-ABS-KEY("Public key cryptography") OR TITLE-ABS-KEY("Public key encryption") OR TITLE-ABS-KEY("asymmetric encryption") OR TITLE-ABS-KEY("Private key cryptography") OR TITLE-ABS-KEY("Private key encryption") OR TITLE-ABS-KEY("symmetric encryption") OR TITLE-ABS-KEY("secret key cryptography") OR TITLE-ABS-KEY("Digital signature") OR TITLE-ABS-KEY("Cryptography") OR TITLE-ABS-KEY("cryptographic hash function") OR TITLE-ABS-KEY("Block cipher") OR TITLE-ABS-KEY("stream cipher") OR TITLE-ABS-KEY("message authentication code") OR TITLE-ABS-KEY("Cryptanalysis") OR TITLE-ABS-KEY("Mathematical foundation" near5 "cryptography") OR TITLE-ABS-KEY("new generation crypto algorithm") OR TITLE-ABS-KEY("new generation of security method") OR TITLE-ABS-KEY("Common encryption technology") OR TITLE-ABS-KEY("data privacy and security") OR TITLE-ABS-KEY("Privacy of data management") OR TITLE-ABS-KEY("Security vulnerabilities in software") OR TITLE-ABS-KEY("Location privacy in geographic application") OR TITLE-ABS-KEY("Authentication technology") OR TITLE-ABS-KEY("Video encryption") OR TITLE-ABS-KEY("E-signature") OR TITLE-ABS-KEY("firewall security") OR TITLE-ABS-KEY("Privacy perserving data management") OR TITLE-ABS-KEY("Next Generation Cryptography") OR TITLE-ABS-KEY("Formal security model")

Table B.1. (Cont'd)

OR TITLE-ABS-KEY ("multiple level security") OR TITLE-ABS-KEY ("Context-based access control") OR TITLE-ABS-KEY ("role based access control") OR TITLE-ABS-KEY ("Management of encrypted data") OR TITLE-ABS-KEY ("Vulnerability management") OR TITLE-ABS-KEY ("Mobile platform security ") OR TITLE-ABS-KEY ("Operating systems security ") OR TITLE-ABS-KEY (" Network security") OR TITLE-ABS-KEY ("Denial of Service attack") OR TITLE-ABS-KEY (" querying encrypted data") OR TITLE-ABS-KEY ("Multi-factor authentication") OR TITLE-ABS-KEY ("Embedded system" near3 security) OR TITLE-ABS-KEY ("trusted computing") OR TITLE-ABS-KEY ("hardware security module") OR TITLE-ABS-KEY ("Cryptographic hardware")

For retrieving patent data, Derwent Database is used. In the coding the 'NEAR' operator is used which is a proximity operator to boost the score of documents if they contain expressions near each other. This way matching analysis is applied, such as "(ICT_TA1) Information Security (including Cybersecurity and Cryptology) NEAR AUTO". Table B.2 below, shows the coding sample for (ICT_TA1) NEAR AUTO.

Table B.2. Coding Sample for AUTO + Information Security Keyword Cluster for Patent Data Retrieval from Derwent Database

ALLD=((("information security" near10 "electric vehicle*") OR ("cybersecurity" near10 "electric vehicle*") ADJ ("cryptology" near10 "electric vehicle*") OR ("cryptography" near10 "electric vehicle*") ADJ ("data privacy and security" near10 "electric vehicle*") OR ("Authentication technology" near10 "electric vehicle*") OR ("Next Generation Cryptography" near10 "electric vehicle*") OR ("Context-based access control") OR ("Mobile platform security" near10 "electric vehicle*") OR ("Operating systems security " near10 "electric vehicle*") OR ("Network security" near10 "electric vehicle*") OR ("trusted computing" near10 "electric vehicle*") OR ("hardware security module" near10 "electric vehicle*") OR ("Cryptographic hardware" near10 "electric vehicle*") AND ("information security" near10 "automo*") OR ("cybersecurity" near10 "automo*") ADJ ("cryptology" near10 "automo*") OR ("cryptography" near10 "automo*") ADJ ("data privacy and security" near10 "automo*") OR ("Authentication technology" near10 "automo*") OR ("Next Generation Cryptography" near10 "automo*") OR ("Context-based access control" near10 "automo*") OR ("Mobile platform security" near10 "automo*") OR ("Operating systems security " near10 "automo*") OR ("Network security" near10 "automo*") OR ("trusted computing" near10 "automo*") OR ("hardware security module" near10 "automo*") OR ("Cryptographic hardware" near10 "automo*") AND ("information security" near5 "Autonomous driv*") OR ("cybersecurity" near5 "Autonomous driv*") OR ("cryptology" near5 "Autonomous driv*") OR ("cryptography" near5 "Autonomous driv*") ADJ ("data privacy and security" near5 "Autonomous driv*") OR ("Authentication technology" near5 "Autonomous driv*") OR ("Next Generation Cryptography" near5 "Autonomous driv*") OR ("Context-based access control" near5 "Autonomous driv*") OR ("Mobile platform security" near5 "Autonomous driv*") OR ("Operating systems security " near5 "Autonomous driv*") OR ("Network security" near5 "Autonomous driv*") OR ("trusted computing" near5 "Autonomous driv*") OR ("hardware security module" near5 "Autonomous driv*") OR ("Cryptographic hardware" near5 "Autonomous driv*") AND ("information security" near5 "connected car") OR ("cybersecurity" near5 "connected car") OR ("cryptology" near5 "connected car") OR ("cryptography" near5 "connected car") ADJ ("data privacy and security" near5 "connected car") OR ("Authentication technology" near5 "connected car") OR ("Next Generation Cryptography" near5 "connected car") OR ("Context-based access control" near5 "connected car") OR ("Mobile platform security" near5 "connected car") OR ("Operating systems security " near5 "connected car") OR ("Network security" near5 "connected car") OR ("trusted computing" near5 "connected car") OR ("hardware security module" near5 "connected car") OR ("Cryptographic hardware" near5 "connected car"));

C. ASSIGNEES PER EACH SUB TECHNOLOGY AREA IN BIBLIOMETRIC ANALYSIS BASED ON PATENTS

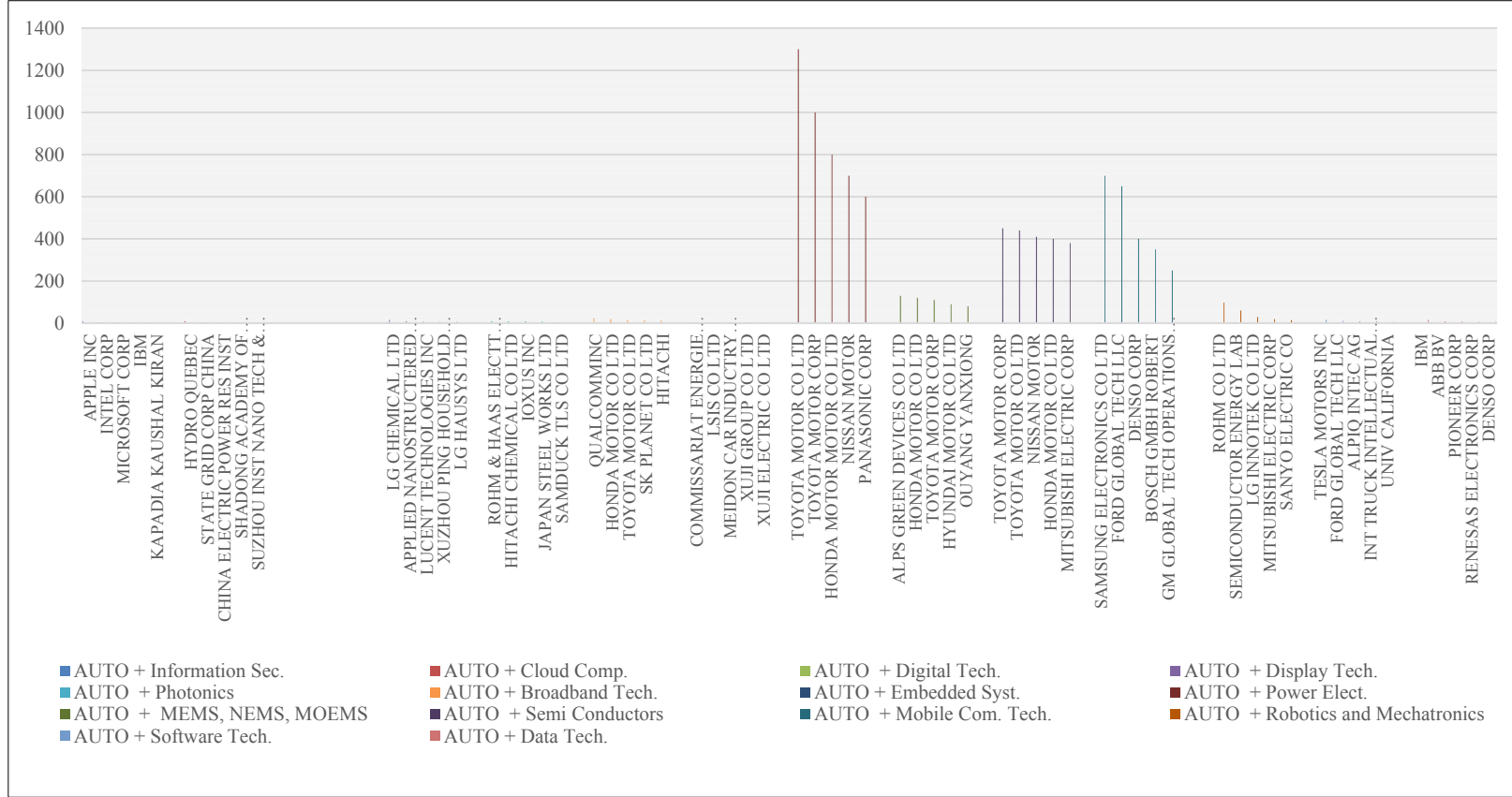


Figure C.1. AUTO-ICT Sector, Top 5 Assignees for Each TA Based On Patents

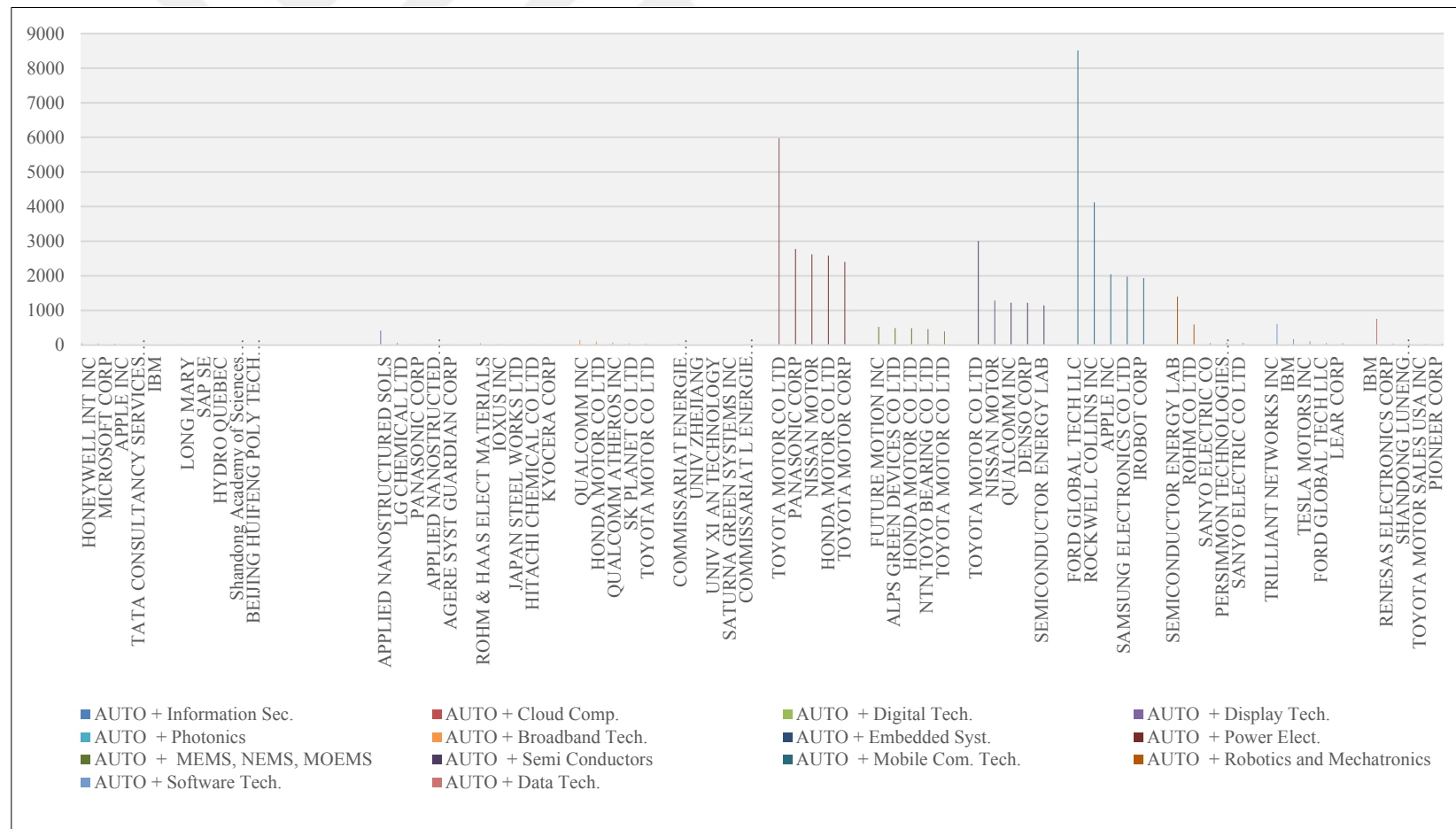


Figure C.2. AUTO-ICT Sector, Top 5 Assignees for Each TA Based On Backward Citations of Patents

D. GLOBAL INDEXES IN DETERMINATION OF EXAMINED COUNTRIES AND COMPANIES

For the determination of countries and companies for Section 5.1.3 - Quantitative Analysis of Market Convergence, primarily results of Section 5.1.1 Quantitative Analysis of Science Convergence and Section 5.1.2 - Quantitative Analysis of Technology Convergence, are taken into consideration. For a better perspective and to crosscheck the pool of determined countries and companies, R&D and innovation performances are also checked and analyzed via global indexes. In this regard, **Global Innovation Index (GII)**³³ and **Global Competitiveness Index (GCI)**³⁴, 2017-2018, and for a better company and/or sector perspective **The Global Innovation 1000 Study** (2018)³⁵, are used.

Table D.1 shows the top 25 rankings of the GII and the GCI in comparison for the years 2017 and 2018, respectively. While Switzerland takes the top place for both indexes and both years, the following countries also do not differ overall. Sweden, Netherlands, USA, UK, Singapore, and Germany are in the top five. The top 25 of both indexes also match with the findings of Section 5.1.1 and Section 5.1.2. Moreover, for the GII 2018 ranking, looking at the indicator of global R&D companies (average expenditure on R&D of the top three global companies) United States of America, Germany, Switzerland, Japan, South Korea, China, United Kingdom, France, Netherlands, and Ireland are the top ten countries.

³³ Global Innovation Index, 2017-2018, Retrieved from <https://www.globalinnovationindex.org/analysis-indicator>

³⁴ Global Competitiveness Index, 2017-2018, Retrieved from <https://reports.weforum.org/global-competitiveness-report-2018/>

³⁵ The 2018 Global Innovation 1000 study, 2018, strategy& PwC, Retrieved from www.strategyand.pwc.com/innovation1000

In addition, for the same index, looking at the High-Tech Export indicator, China, South Korea, Malaysia, Singapore, and Viet Nam share the top spot by score. Czech Republic, Mexico, Thailand, Hungary, and France following them in the top ten. On the other hand, looking at the Ccompetition dimension under the GCI 2018 ranking, Singapore, Hong Kong, United Arab Emirates, Netherlands, Luxembourg, Ireland, New Zealand, Switzerland, USA and UK come front in the top ten.

Furthermore, **The Global Innovation 1000 Study** is taken into consideration for having a better company wise and sectoral perspective in the global R&D ecosystem. Table D.2 below, lists the Global Innovation 1000 Study 2018 ranking for the top 25 largest corporate R&D spenders from the years 2017-2018 worldwide. Company name, country, and sector, R&D expenditures, revenue, and R&D intensity (R&D expenditure as a percentage of revenue) for the years 2017-2018 are respectively given. These companies and countries can easily be considered as global dominant R&D actors, as well as dominant actors from the sectoral perspective. Without any filters in the top 25 United States is the top country followed by Germany. Amazon.com Inc. is the top company, in the Retail sector (Internet and Direct Marketing Retail-Digital Retail). Looking at the sectors explicitly, Pharmaceuticals, Automobiles and ICTs sectors (such as Internet Software and Services, Technology Hardware, Storage and Peripherals, and Semiconductors and Semiconductor Equipment) come on top (Table D.2).

Filtering the top 25 by automotive and ICT related sectors, these sectors and related companies can be seen at the top as well. Thus, domain automotive and ICTs companies are (Table D.3), Google - Alphabet Inc., Volkswagen Aktiengesellschaft, Samsung Electronics Co., Ltd., Intel Corporation, Microsoft Corporation, Apple Inc., Toyota Motor Corporation, Ford Motor Company, Facebook, Inc., General Motors Company, Daimler AG, Honda Motor Co., Ltd., Oracle Corporation, Cisco Systems, Inc., and Bayerische Motoren Werke Aktiengesellschaft (BMW).

The GII is a yearly report published in collaboration with Cornell University, INSEAD, and WIPO. PwC's Strategy& is also a knowledge partner. Every year, the GII ranks the innovation performance of nearly 130 economies around the world. The GII consists of input and output sub-indexes. Generally, the GII model is revised every year in a transparent exercise. In 2017 and 2018 same model is used for the pillar and sub-pillars. The Innovation Input Sub-Index is comprised of five input pillars that capture elements of the national economy that enable innovative activities: (1) Institutions, (2) Human capital and research, (3) Infrastructure, (4) Market sophistication, and (5) Business sophistication. The Innovation Output Sub-Index provides information about outputs that are the results of innovative activities within the economy. There are two output pillars: (6) Knowledge and technology outputs and (7) Creative outputs.

The GCI is also a yearly report, published by the World Economic Forum (WEF). The GCI assesses the competitiveness landscape of 140 economies, providing unique insight into the drivers of economic growth in the era of the Fourth Industrial Revolution. Taken under consideration of 12 pillars grouped into four categories (enabling environment, human capital, markets and innovation ecosystem), institutions, infrastructures, ICT adoption, macroeconomic stability, health, skills, product market, labour market, financial system, market size, business dynamism and innovation capability are examined.

The Global Innovation 1000 Study analyses spending at the world's 1000 largest publicly listed corporate R&D spenders, conducted annually by Strategy&, part of the PwC network.

Table D.1. GII and GCI, 2017-2018 Comparison, Top 25

Rank	Global Innovation Index		Global Competitiveness Index	
	2017 Ranking (127 Countries)	2018 Ranking (126 Countries)	2017 Ranking	2018 Ranking
1	Switzerland	Switzerland	Switzerland	Switzerland
2	Sweden	Netherlands	Singapore	United States
3	Netherlands	Sweden	United States	Singapore
4	United States	United Kingdom	Netherlands	Netherlands
5	United Kingdom	Singapore	Germany	Germany
6	Denmark	United States	Sweden	Hong Kong
7	Singapore	Finland	United Kingdom	Sweden
8	Finland	Denmark	Japan	United Kingdom
9	Germany	Germany	Hong Kong	Japan
10	Ireland	Ireland	Finland	Finland
11	South Korea	Israel	Norway	Norway
12	Luxembourg	South Korea	Denmark	Denmark
13	Iceland	Japan	New Zealand	New Zealand
14	Japan	Hong Kong	Taiwan	Canada
15	France	Luxembourg	Canada	Taiwan
16	Hong Kong	France	United Arab Emirates	Israel
17	Israel	China	Belgium	United Arab Emirates
18	Canada	Canada	Qatar	Austria
19	Norway	Norway	Austria	Luxembourg
20	Austria	Australia	Luxembourg	Belgium
21	New Zealand	Austria	France	Australia
22	China	New Zealand	Australia	France
23	Australia	Iceland	Ireland	Malaysia
24	Czech Republic	Estonia	Israel	Ireland
25	Estonia	Belgium	Malaysia	South Korea

Table D.2. The Global Innovation 1000 Study, Top 25

2018 Rank	Company Name	Country	Sector	R&D Expense (in USD billions, income statement exchange rate)		Total Revenue (in USD billions, income statement exchange rate)		R&D Intensity (%)	
				2017	2018	2017	2018	2017	2018
1	Amazon.com, Inc.	US	Internet and Direct Marketing Retail	16.09	22.62	135.99	177.87	11.8%	12.7%
2	Alphabet Inc.	US	Internet Software and Services	13.95	16.23	90.27	110.86	15.5%	14.6%
3	Volkswagen Aktiengesellschaft	Germany	Automobiles	13.82	15.77	260.89	277.00	5.3%	5.7%
4	Samsung Electronics Co., Ltd.	S. Korea	Technology Hardware, Storage and Peripherals	14.33	15.31	188.97	224.27	7.6%	6.8%
5	Intel Corporation	US	Semiconductors and Semiconductor Equipment	12.74	13.10	59.39	62.76	21.5%	20.9%
6	Microsoft Corporation	US	Software	13.04	12.29	85.32	89.95	15.3%	13.7%
7	Apple Inc.	US	Technology Hardware, Storage and Peripherals	10.05	11.58	215.64	229.23	4.7%	5.1%
8	Roche Holding AG	Switzerland	Pharmaceuticals	11.83	10.80	54.01	57.20	21.9%	18.9%
9	Johnson & Johnson	US	Pharmaceuticals	9.10	10.55	71.89	76.45	12.7%	13.8%
10	Merck & Co., Inc.	US	Pharmaceuticals	10.12	10.21	39.81	40.12	25.4%	25.4%
11	Toyota Motor Corporation	Japan	Automobiles	9.77	10.02	267.44	259.85	3.7%	3.9%
12	Novartis AG	Switzerland	Pharmaceuticals	9.57	8.51	49.39	50.14	19.4%	17.0%
13	Ford Motor Comp.	US	Automobiles	7.30	8.00	151.80	156.78	4.8%	5.1%
14	Facebook, Inc.	US	Internet Software and Services	5.92	7.75	27.64	40.65	21.4%	19.1%
15	Pfizer Inc.	US	Pharmaceuticals	7.87	7.66	52.82	52.55	14.9%	14.6%
16	General Motors Company	US	Automobiles	8.10	7.30	149.18	145.59	5.4%	5.0%
17	Daimler AG	Germany	Automobiles	7.81	7.08	184.03	197.32	4.2%	3.6%
18	Honda Motor Co.	Japan	Automobiles	6.51	7.08	137.48	131.81	4.7%	5.4%
19	Sanofi	France	Pharmaceuticals	6.21	6.57	41.68	43.47	14.9%	15.1%
20	Siemens	Germany	Industrial Conglomerates	5.82	6.10	94.13	98.16	6.2%	6.2%
21	Oracle Corp.	US	Software	6.82	6.09	37.05	37.73	18.4%	16.1%
22	Cisco Systems, Inc.	US	Communications Equipment	6.30	6.06	49.25	48.01	12.8%	12.6%
23	GlaxoSmithKline plc	UK	Pharmaceuticals	4.90	6.05	37.70	40.80	13.0%	14.8%
24	Celgene Corporation	US	Biotechnology	4.47	5.92	11.23	13.00	39.8%	45.5%
25	BMW	Germany	Automobiles	5.16	5.91	113.07	118.49	4.6%	5.0%

Table D.3. The Global Innovation 1000 Study, Filtered by Automotive and ICT

2018 Rank	Company Name	Country	Sector	R&D Expense (in USD billions, income statement exchange rate)		Total Revenue (in USD billions, income statement exchange rate)		R&D Intensity (%)	
				2017	2018	2017	2018	2017	2018
2	Alphabet Inc.	US	Internet Software and Services	13.95	16.23	90.27	110.86	15.5%	14.6%
3	Volkswagen	Germany	Automobiles	13.82	15.77	260.89	277.00	5.3%	5.7%
4	Samsung Electronics Co., Ltd.	S. Korea	Technology Hardware, Storage and Peripherals	14.33	15.31	188.97	224.27	7.6%	6.8%
5	Intel Corporation	US	Semiconductors and Semiconductor Equipment	12.74	13.10	59.39	62.76	21.5%	20.9%
6	Microsoft Corporation	US	Software	13.04	12.29	85.32	89.95	15.3%	13.7%
7	Apple Inc.	US	Technology Hardware, Storage and Peripherals	10.05	11.58	215.64	229.23	4.7%	5.1%
11	Toyota Motor Corporation	Japan	Automobiles	9.77	10.02	267.44	259.85	3.7%	3.9%
13	Ford Motor Company	US	Automobiles	7.30	8.00	151.80	156.78	4.8%	5.1%
14	Facebook, Inc.	US	Internet Software and Services	5.92	7.75	27.64	40.65	21.4%	19.1%
16	General Motors Company	US	Automobiles	8.10	7.30	149.18	145.59	5.4%	5.0%
17	Daimler AG	Germany	Automobiles	7.81	7.08	184.03	197.32	4.2%	3.6%
18	Honda Motor Co., Ltd.	Japan	Automobiles	6.51	7.08	137.48	131.81	4.7%	5.4%
21	Oracle Corporation	US	Software	6.82	6.09	37.05	37.73	18.4%	16.1%
22	Cisco Systems, Inc.	US	Communications Equipment	6.30	6.06	49.25	48.01	12.8%	12.6%
25	BMW	Germany	Automobiles	5.16	5.91	113.07	118.49	4.6%	5.0%

E. DATA FOR TURKEY REGARDING QUANTITATIVE ANALYSIS

E.1. Data for Turkey for Quantitative Analysis of Science Convergence Regarding ICT-Based AUTO Sector

As the reason for this thesis being written in Turkey, available data is covered as a special section. For ICT-based AUTO sector data regarding total publication counts between the years 2007-2017 by sub-technology areas are given in Figure E.1. Only available data is shown in the figure below, meaning sub-technology areas with zero counts are eliminated. In this case, sub-technology areas given below have zero counts are, AUTO + Information Security, AUTO + Display Tech., AUTO + MEMS, NEMS, MOEMS and AUTO + Software Technologies.

On the other hand, while the total count for Turkey is 225, it can be seen that most counts are retrieved from power electronics, semiconductors, data technologies and robotics and mechatronics, following with mobile communication technologies, cloud computing and embedded systems but with a very fewer counts. In this regard, comparing the most frequent sub-technology areas with ICT-based AUTO sector for Turkey, the possibility of Turkey developing niche technologies and engaging in global competitiveness in related areas, is considered low.

Comparing Turkey data with other countries, from looking at Figure 5.7 again, with a total count of 225 publications overall, this count makes Turkey to get ahead of countries like Spain, Austria, Sweden, Taiwan, Singapore, Portugal, Hong Kong and Australia. However, it should be noted that Turkey does not make the the top five or ten countries for any of the sub-technology areas.

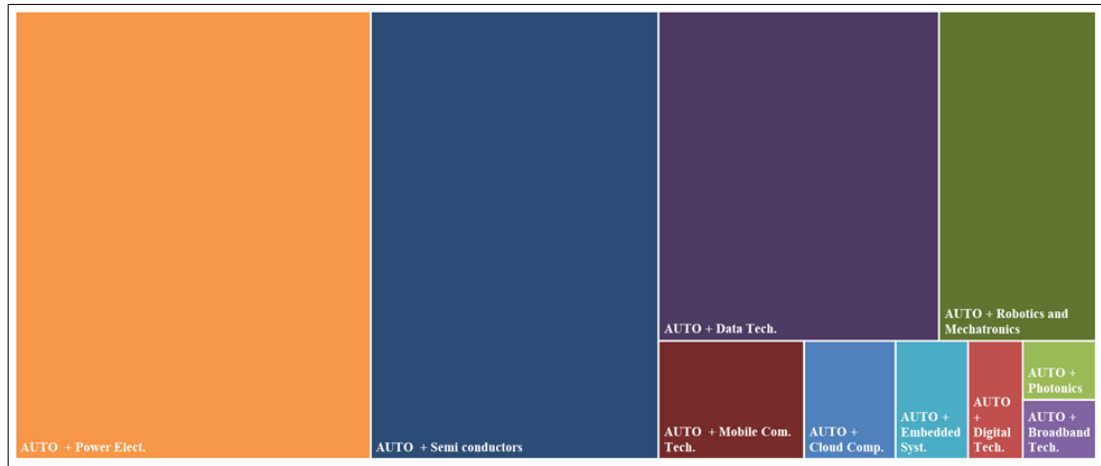


Figure E.1. ICT-Based AUTO, Frequency of ICT TAs for Turkey Based On Total Publication Counts, 2007-2017

E.2. Data for Turkey for Quantitative Analysis of Science Convergence Regarding AUTO-Based ICT Sector

For AUTO-based ICT sector data regarding total publication counts between the years 2007-2017 by sub-technology areas are given in Figure E.2. Unlike ICT-based AUTO sector, there is no sub-technology area with zero counts in this case.

On the other hand, while the total count for Turkey is 208, it can be seen that most counts are retrieved from sub-technologies EHV technologies, following with engine and engine transmission components (powertrain), automotive material technologies, automotive embedded systems, battery technologies and lastly innovative design. EHV technologies shows a great difference from the other sub-technology areas with almost having the half of the counts to itself. The results for Turkey again match with the results for the most frequent sub-technology areas for AUTO-based ICT sector. Again, concentration of EHV technologies is also similar. This result suggests that Turkey is also focusing on EHV technologies, on the other hand the possibility of developing technologies for niche areas is again seemingly low, especially integrating the results with ICT-based AUTO sector, above.

Comparing Turkey with other countries, from looking at the Figure 5.13 again, with a total count of 208 publications overall, this count makes Turkey to get ahead of countries like Sweden, Iran and Australia. However, it should be noted that Turkey does not make the top five or ten countries for any of the sub-technology areas.

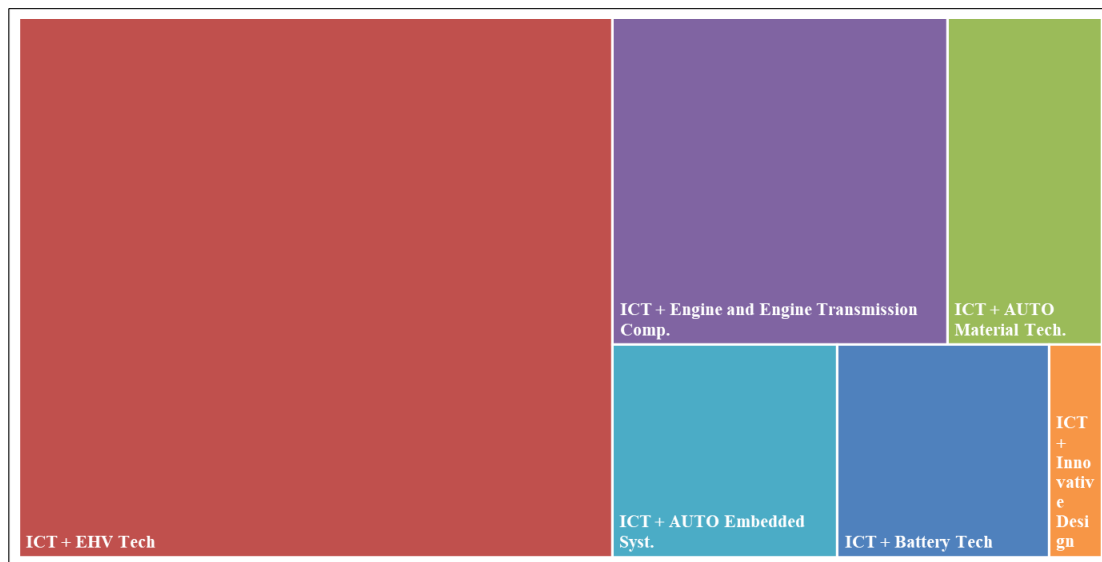


Figure E.2. AUTO-Based ICT, Frequency of AUTO TAs for Turkey Based On Total Publication Counts, 2007-2017

E.3. Data for Turkey for Quantitative Analysis of Market Convergence

Turkey is the second in commercial vehicle production in Europe, whereas fifth and fifteenth in Europe's and World's automotive production list, respectively (Invest in Turkey, 2021). Turkish automotive industry faced -1,3% change in production compared with last year (Automotive Industry Association, 2021). 61% change in total market, 59% change in imports and -6% change in exports compared with last year. Notable examples of global brands with product development, design, and engineering activities in Turkey include Ford, Fiat, Daimler, and AVL. FORD OTOSAN's R&D center is one of Ford's three largest global R&D centers, which focuses on engine and powertrain technologies, electrical and electronic systems of the vehicles (FORD OTOSAN, 2021).

First of all, main RDI policy and strategy documents of Turkey are investigated. Both the Tenth Development Plan (2014-2018) and the Eleventh Development Plan (2019-2023) (Presidency of Strategy and Budget (SBB), 2019) contain policies and measures regarding the cross-sectoral approach of automotive and ICT sectors.

For example, in the Tenth Development Plan (Saraçoğlu, 2014), it is stated that with the increase in direct access to information and various products and the widespread use of the internet, consumer preferences in fields such as electronics and automotive have increased. Therefore, developing technologies to enter new business areas in the electronics sector is one of the measures. In this context, developing the application possibilities of dual-purpose technologies to increase the integration towards the automotive sector is prioritized.

In the Eleventh Development Plan (SBB, 2019), electronics and automotive sectors are among the priority sectors. Transportation and automotive are also prioritized sectors within the scope of policies and measures addressing electronics sector. For example, it is aimed to support domestic production of hardware and software products used in M2M and IoT ecosystem including all vertical sectors. On the other hand, high-tech domestic brand vehicle production is one of the objectives of the automotive sector. In that context, automotive sector policies and measures include, supporting the improvement of technology and production capabilities in areas such as sensors, batteries, fuel cells and software, connected and autonomous vehicles, smart mobility, R&D activities in “automotive information technologies”; and strengthening the integration between the automotive sector and other sectors such as electronics and software.

In addition, related to priority sectors such as, automotive and electronics, digital transformation is considered as an accelerator policy. In that regard, related policies and measures include, supporting the digital transformation projects and the development of systems necessary for the digital transformation process focusing on

the priority sectors; and the establishment of the industrial cloud platform for the automotive sector.

Another recent related strategy document is Turkey's 2023 Industry and Technology Strategy (Ministry of Industry and Technology, 2019). The Strategy Document shares similarity in scope and content of such strategy and action plans, such as the Eleventh Development Plan. The Strategy Document emphasizes the importance of proactive policies addressing disruptive technologies for the automotive sector, for instance, AI and connectedness. In that regard, The Strategy Document also aims to support the development of sectoral roadmaps and technology roadmaps for KETs that disruptively changes the dynamics of the sectors, such as *5G and beyond, AI and ML, robotics and autonomous systems, IoT, big data, cybersecurity, blockchain, additive manufacturing, high-performance computing, unmanned aerial vehicles*. It is especially predicted that the transformation into connected, electric and autonomous vehicles in the automotive sector will be accelerating between the years 2020-2030. In that regard, it is stated that this transformation process is also accelerating by the restrictions imposed by regulation in European and Asian countries. In addition, it is predicted that from 2025, *vehicle-to-everything (V2X) communication systems will be mandatory in new EHV's. Connected, electric and autonomous systems* will require the addition of a large number of high-tech products and sub-systems such as batteries, electric motors, special cooling systems, special high-speed in-vehicle communication buses, sensors, autonomous decision modules, electronic actuators. The use of these new solutions in vehicles requires an intensive accreditation and certification process and test infrastructures. The number of test centers in Europe where the certification of accredited and high-tech solutions is limited and they do not meet the existing demand. For this matter, The Strategy Document prioritizes *mobility sector* as an ecosystem, which includes automotive sector, and aims to support the R&D and test infrastructures for autonomous vehicles and related KETs, as well. In addition, mobility sector and related KETs (*autonomous and semi-autonomous concept vehicles, ADAS, V2X, advanced material technologies, IoT, 5G and beyond, battery*

and energy storage technologies, etc.) are supported via Tech-Driven Industry Program, coordinated by Ministry of Industry and Technology.

Another related strategy document is National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan (Ministry of Transport and Infrastructure, 2019). There are five main strategic goals of the ITS Strategy which are; developing the ITS infrastructure, providing a sustainable smart mobility, ensuring road and driving safety, creating a livable environment and conscious society, ensuring data sharing and security. The main ITS applications and KETs which will be focused on are determined as *smart vehicles (ADAS, connected and autonomous vehicles); smart roads (passenger information systems, smart interactions, sensors); smart cities, smart energy systems, electric vehicles, environment friendly transportation infrastructure, integration systems, information and security (big data, data security, cybersecurity)*.

Accordingly, there are several ongoing cross-sectoral projects in Turkey. One of them is, “Autonomous and Connected Vehicle Technologies Development, Education and Test Infrastructure Project” in collaboration of Istanbul Development Agency and TÜBİTAK. Moreover, considering the aforementioned global trends, such demand-based mobility, data-driven business models, autonomous and sharing vehicles, one of the landmark projects of Turkey established in 2018, which is Turkey's Automobile Initiative Group Inc. (TOGG)”, namely Turkey’s Automobile. TOGG is founded by the companies which are the leaders in their fields; Anadolu Group, BMC, Kök Group, Turkcell and Zorlu Group under the initiative of The Union of Chambers and Commodity Exchanges of Turkey (TOBB). TOGG is introducing C-SUV models which is expected to begin production in 2022. The project objectives include developing a native electric and connected platform, completely designed and developed by TOGG engineers and fully electric driving experience. Additionally, “Level 2+” autonomous driving with advanced driving assistance systems including slow traffic pilot.

One of the important actors for the automotive sector in Turkey is "Automotive Technology Platform, (OTEP)". The foundation of the OTEP supported by TÜBİTAK, in 2008, and the platform has been very successful ever since in engaging different actors of the automotive ecosystem in Turkey. There are total of fifty-six members/partners of OTEP, which include automotive sector dominant actors from industry (such as FORD OTOSAN, HONDA TURKEY, Karsan, Mercedes Benz Turkey, TEMSA, Türk Traktör, TOFAŞ, etc.), university (METU, Sabancı University, Istanbul Technical University, etc.), government (TÜBİTAK Marmara Research Center (MAM), Presidency of The Republic of Turkey, Investment Office (Invest in Turkey) Automotive Department, Ministry of Industry and Technology Department of Strategy) and non-profit organizations (Association of Automotive Parts and Components Manufacturers, Automotive Manufacturers Association, Automotive Industry Exporters Association). Recent studies of the OTEP include *battery technologies, electrification, software for automotive, digital transformation, IoT, big data, connected and autonomous vehicles, materials technologies, and test and verification technologies* (OTEP, 2021).

Moreover, there are technology roadmapping studies coordinated by TÜBİTAK that are also integrated with call plannings for TÜBİTAK support mechanisms (recent call plan conducted for 2019-2021 period) and the aforementioned Tech-Driven Industry Program. Related technology roadmapping studies include "Embedded Systems for Automotive and Machinery Applications" which was conducted in 2014. In 2016, "Smart Manufacturing Systems Technology Roadmap" was conducted that includes eight critical technologies, ten strategic objectives and twenty-nine critical products for the digital transformation of industry for Turkey.

In 2018, "Smart Manufacturing Systems Technology Roadmap" adopted as "Digital Transformation Roadmap" for Turkey. Most recent ongoing technology roadmapping studies, which are conducted under the auspices of Science, Technology and Innovation Policies Council Under The Turkish Presidency (STIPC) and with the technical support of TÜBİTAK, cover KETs like AI, cybersecurity, big data and cloud

computing, engine technologies that are planned to include critical targets for technologies and products for automotive and ICT cross-sectoral approaches. Accordingly, TÜBİTAK prioritized RDI subjects for 2021 also include cross-sectoral approaches under automotive and ICT sectors; most relatedly *embedded systems for automotive sector, such as autonomous driving, ADAS, V2X, autonomous and semi-autonomous vehicles*.

Lastly, recent support mechanisms for the development of consortiums are considered effective for fostering cross-sectoral approaches while supporting the development of KETs (multi-, cross-, and interdisciplinary areas). They are also designed to be integrated in the value and supply chain. One of the consortium supports is the “Centres of Excellence Program, Call for High-Technology Platforms” (STIP, 2021), which aims to support the development of high-technology platforms to realize technology transfer between leading research institutions and the private sector. The targeted Technology Readiness Level should be between TRL 3 and 6. The other consortium support is “Industrial Innovation Networks (SAYEM)” (TÜBİTAK, 2021).

With SAYEM it is aimed to support private sector firms, especially those that contain an R&D and product design centre, to form a network with other firms that take place in the value chain of the targeted technology-based product together with end-users, technology development zones, and universities, for co-creating high value-added products and technologies for the market. The targeted Technology Readiness Level should be between TRL 5 or 6 and 9, thereby targeting technological innovation that is closer to the market.

F. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

G. CURRICULUM VITAE

H. TURKISH SUMMARY/TÜRKÇE ÖZET

Teknolojik gelişmeler, ekonomik büyümede ve ekonomilerin dönüşümünde önemli bir rol oynamaktadır. Küresel eğilimleri inceleyen tüm analizler, önümüzdeki yıllar için, yakınsamanın özellikle teknoloji yakınsamasının sektörler üzerindeki yıkıcı etkisini vurgulamakta, sonuç olarak sektörlerin dönüşümü ile yeniden tanımlanmasını başlıca öne çıkan eğilimlerden biri olarak belirtmektedir. Yeni ekonomide, baskın ekonomik sektör, varlık yaratma altyapısını sağlayan birden fazla yakınsayan sektör tarafından yaratılmaktadır. Böylelikle yakınsama tüm sektörlerin temeli haline gelmekte ve ekonominin ve sektörlerin dönüşüm eşiğini düşürmektedir (Harvard Business Review, 2012; MGI, 2013; Gartner, 2014; KPMG, 2014; IBM, 2016; OECD Internet Economy Outlook, 2012, 2017a, OECD STI Outlook 2016, 2018; Ernst & Young Global Megatrends, 2016, 2018, 2020; NATO, 2020).

Yukarıda bahsedilen olgunun en öne çıkan örneklerinden biri her sektörü hızla etkilemeye devam eden dijital dönüşümdür. Günlük yaşamdan savunma, otomotiv, sağlık sektörleri gibi kritik alanlara kadar her alanda bilgi ve iletişim teknolojilerinin (BİT) kullanılması sektör dinamiklerinde çok önemli değişiklikleri ortaya çıkarmaktadır. Dijital dönüşümün bir örneği olarak, geleneksel medya sektörü ile telekomünikasyon sektörü, mobil teknolojiler ve tüketici elektroniği gibi dijital teknolojilerin yakınsamasından doğan yeni medya sektörü verilebilir. Başka bir örnek ileri malzeme teknolojilerinin sektörlere etkisi olarak belirtilebilir. Öte yandan, tarım ve gıda gibi geleneksel sektörler de bilimsel tabanlı ya da pazar odaklı olan yakınsama etkileri nedeniyle farklı dönüşümler yaşamakta ve ortaya tarım-gıda (agri-food), biyo-dijital sektörleri gibi yeni sektörler ile farklı sistemik yaklaşımlar çıkmaktadır. Diğer bir örnek, kozmetik sektörünün yanı sıra gıda sektörü ile yaşam bilimleri sektörünün yakınsaması olan fonksiyonel gıdalar olarak verilebilir.

Ayrıca, teknolojik yakınsamanın en önemli çıktılarından biri, yeni sektörlerin ve sektörler arası yaklaşımların ortaya çıkmasına sebep olan kilit etkinleştirici teknolojilerdir (KET). Örneğin, MGI'nın (2013) çalışmasında aralarında otonom ve yarı otonom araçlar da olan on iki KET'ten bahsedilmektedir. Belirtilen çalışma, 2025 yılına kadar on iki KET'in uygulamalarından kaynaklanan potansiyel ekonomik etkinin yıllık on trilyon doların üzerinde olacağını hesaplamaktadır. Ayrıca, NATO Bilim ve Teknoloji Eğilimleri 2020-2040 Belgesi, ortaya çıkan, yıkıcı ve yakınsak teknolojilerin önümüzdeki yirmi yıl içinde sosyo-ekonomik, bilimsel ve teknolojik ortamı tanımlayacağını öngörmektedir. Bu teknolojilerin ortak özellikleri akıllı, birbirine bağlı, dağıtılmış ve dijital olmalarıdır. Örneğin, veri-yapay zekâ-otonom sistemler-biyoteknoloji-nanoteknoloji-malzeme-iletişim teknolojileri-pil teknolojileri; veri-uzay-kuantum-genetik-biyo-üretim teknolojileri; uzay-hipersonik-malzeme teknolojileri (NATO, 2020, s. 23-26).

Ulusal, bölgesel veya sektörel yenilik sistemi yaklaşımları, çeşitli aktörler ve dinamikler arasındaki etkileşimleri haritalamak ve açıklamak için yaygın olarak kullanılmaktadır. Ancak, yukarıda bahsedilen örneklerle ilgili olarak, yenilik sistemleri literatüründe iki veya daha fazla sektörün yakınsama durumunu anlamak ve analiz etmek açısından bir yaklaşım ya da yöntem bulunmamaktadır. Dolayısıyla, teknoloji yakınsaması ve KET'lerin tam potansiyelini elde etmek, zorlukları adresleyebilmek, ekonomiler, sektörler ve yenilik sistemleri üzerindeki olası etkilerini ele alarak tedbirler geliştirmek için mevcut yaklaşımların ve ölçüm yöntemlerinin geliştirilmesi gerektiği ortaya çıkmaktadır.

Örneğin, sektörel yenilik sistemleri (Sectoral Innovation System - SIS), sadece bir baskın sektörün dinamikleriyle ilgilenmektedir. SIS yaklaşımı, ilgili/destekleyici sektörlerin bağlantılarına ve karşılıklı bağımlılıklarına da dikkat ederken (Malerba 2002a, 2004), teknoloji yakınsamasının sektörler arası dinamiklere etkisini gözlemlemekte iyileştirmeye açık durumdadır. Son zamanlarda yakınsama literatürü sektörlerin dinamiklerine yönelik gelişmeler içermekle birlikte sistemik yaklaşımları kapsamamaktadır. Bu nedenle yakınsama ve yenilik sistemleri literatürünü birlikte

çalışmak yepyeni bir çalışma alanı olarak değerlendirilmektedir. Başka bir deyişle, hem yakınsama hem de yenilik sistemleri literatüründe, teknoloji yakınsamasını ve sektörler arası birlikte evrimleşme üzerindeki etkisini ele alarak yaklaşımları karşılaştıran ya da birden fazla baskın sektörü odağına koyarak gözlemleyen ve/veya analiz eden bir çalışma bulunmamaktadır.

Bu nedenle, bu tezde ana araştırma sorusu aşağıdaki gibi belirlenmiştir:

- (1) Yenilik Sistemleri yaklaşımları perspektifinde, teknoloji yakınsamasına dayalı bir sektörler arası birlikte evrimleşme süreci var mı?

Ana araştırma sorusuyla ilişkili olarak tezin iki yardımcı araştırma sorusu daha vardır:

- (2) Mevcut yenilik sistemi literatüründe, teknoloji yakınsamasının birden fazla baskın sektörün birlikte evrimleşmesi üzerindeki etkilerini incelemeye yönelik boşluklar nelerdir?
- (3) Sektörler arası birlikte evrimleşmenin kavramsallaştırılmasına dayalı “kilit etkinleştirici teknolojilerin (KET)” oluşumuyla ilgili dinamikleri anlamamanın avantajları nelerdir?

Tez çalışması yukarıda verilen araştırma sorularıyla ilgili olarak yedi adımda gerçekleştirilmiştir. Bu adımlar aşağıdaki gibidir:

1. Adım “Teorik Arka Plan” dır. Bu adım için, teknoloji yakınsaması ve sektörler arası birlikte evrimleşme perspektifinde yenilik sistemleri (IS)³⁶ ile ilgili literatür gözden geçirilmiştir (Ulusal Yenilik Sistemleri (NIS), Bölgesel Yenilik Sistemleri (RIS), Sektörel Yenilik Sistemleri (SIS) ve Karmaşık Yenilik Sistemleri (CIS)). IS

³⁶ IS: Innovation Systems; NIS: National Innovation Systems; RIS: Regional Innovation Systems; SIS: Sectoral Innovation Systems; CIS: Complex Innovation Systems.

literatüründe son yıllarda erişilen olgunluk seviyesine uygun olarak IS aktörlerinin birlikte evrimleşmesi kavramına daha fazla ilgi gösterildiği gözlemlenmektedir. Bununla birlikte, birden fazla sistemin (esas olarak sektörlerin) birlikte evrimleşmesi hâlâ yeni bir çalışma alanı olduğu değerlendirilmektedir.

Öte yandan, teknoloji yakınsaması literatürü, IS literatüründen de ayrı bir alan olarak kalmaktadır, bu nedenle literatür taramasında son yıllardaki bilim yakınsaması, pazar yakınsaması ve sanayi yakınsaması çalışmalarını içerecek şekilde gözden geçirilmiştir. Teknoloji yönetimi çalışmaları, firma perspektifinden teknoloji yakınsamasının önemini özetlemektedir. Ek olarak, teknoloji yakınsamasını analiz etme yöntemleri geniş bir şekilde tartışılmıştır (Jeong vd., 2015). Yeni nesil teknolojik yeniliğe öncülük etme konusunda teknoloji yakınsamasının rolü göz önüne alındığında literatürde sıklıkla vurgulandığı görülmektedir (Athreye ve Keeble, 2000; Morillo vd., 2003; Curran vd., 2010; Curran ve Leker, 2011; Preschitschek vd., 2012; Karvonen ve Kässä, 2013).

Yıkıcı etkisi kabul edilen teknoloji yakınsaması çeşitli ekonomik aktörler tarafından bilinmektedir ancak teknoloji yakınsamasının nasıl geliştiğini gözlemleyen tüm teknolojik alanları kapsayacak şekilde deneysel olarak araştıran çok az çalışma bulunmaktadır (Roco ve Bainbridge, 2002; Curran ve Leker, 2011; Jeong vd. 2015). Başka bir deyişle, literatürde sınırlı sayıda çalışma, teknoloji yakınsamasına ilişkin kapsamlı ve kanıtsal bir görüş sağlamaktadır (Jeon vd. 2015).

Tez kapsamında ana araştırma birimi sektörler olduğu için SIS literatürüne daha fazla odaklanılmıştır. SIS yaklaşımına göre, bir baskın sektörün dinamiklerine (firmalar, firmalar dışındaki diğer aktörler, ağlar, talep, kurumlar, bilgi yaratma, etkileşim) ve bu dinamiklerin sektör içinde birlikte evrimleşmesine yönelik çalışmalar bulunmaktadır. SIS yaklaşımı, baskın sektörle ilgili/destekleyici sektörlerin bağlantılarını, tamamlayıcılıkları ve karşılıklı bağımlılıklarını da kapsamaktadır; ve bunları sektörel sınırların oluşması açısından çok önemli görmektedir. Yine de SIS yaklaşımı, birden

fazla baskın sektörü odağına koymamaktadır. Dolayısıyla, yakınsamanın sektörler arası dinamikler üzerine etkilerini açıklamak açısından iyileştirmeye açık durumdadır.

Bu konuda, literatür taramasından elde edilen girdiler kullanılarak, **Sektörler Arası Yenilik Sistemi (CSIS)** yaklaşımının olası yararlarını anlamak için mevcut IS yaklaşımları ile CSIS yaklaşımının karşılaştırılmasına ilişkin dokuz kriterde karşılaştırma tablosu hazırlanmıştır (Tablo 2.1). Bu kriterler: (1) Tanım/Ana Analiz Birimi, (2) Sektörün Sınırları/Farklı Sektörler Arasındaki İlişki, (3) Teknoloji Yakınsamasına Odaklanma, (4) (Sektörler Arası) Birlikte Evrimleşme Perspektifi, (5) Sanayi Yakınsamasına Odaklanma, (6) Yeni Sektörlerin Ortaya Çıkışı, (7) Sanayinin İç ve Dış Faktörlerinin Birlikte Evrimleşmesi, (8) KET'lere Odaklanma, ve (9) IS Yaklaşımları ile Arasındaki İlişki'dir.

Ek olarak, ana araştırma sorusu ile uyumlu olarak, teknoloji itme ve pazar çekme etkileri arasındaki ilişkinin bilim ve teknoloji yakınsamalarından pazar yakınsamasına ve netice de sanayi yakınsamasının oluşumuna yönelik itme-çekme dinamiğini incelemek için talep odaklı yenilik politikaları literatürü de araştırılmıştır. Tezin literatür taraması **“Bölüm 2 - Teorik Arka Plan”** olarak sunulmuş ve CSIS yaklaşımının ana unsurlarının belirlenmesi amaçlanmıştır. Bu tezin temel amacı ile ilgili olarak, tüm bu bulgular, CSIS yaklaşımı için analiz yöntemini geliştirmek için girdi olarak kullanılmış (Adım 3) ve durum çalışmasında otomotiv ve BİT sektörleri (Adım 4) için uygulanmıştır.

2. Adım “Tanımlayıcı Çalışma” olup iki bölümden oluşan **“Bölüm 3 – Sektörler Arası Dinamikler için Tanımlayıcı Çalışma”** olarak sunulmuştur. Tanımlayıcı çalışma, sektörler arası ve birlikte evrimleşme yönlerini gösteren, özellikle teknoloji yakınsamasının etkisiyle dönüşmekte olan sektörlerin daha iyi anlaşılması için literatür taramasına tamamlayıcı olarak çalışılmıştır. Tanımlayıcı çalışma ile, sistemik yaklaşımlarla ilgili boşlukları vurgulamak ve durum çalışmasında çalışılabilecek farklı sektörlerin belirlenmesi amaçlanmıştır. Bu nedenle, “yakınsayan sanayiler” ve “sanayi yakınsaması” terimlerine odaklanılarak iki kısımlı bir çalışma gerçekleştirilmiştir. İlk

kısımda, belirtilen anahtar kelimeler kullanılarak 2007-2017 yılları arasında SCOPUS'tan elde edilen yayın verilerine dayalı bibliyometrik analiz gerçekleştirilmiştir. VOSviewer ile ülkeler bazında terimlerin birlikte sıklığı ve ortak yazarlık analizleri hazırlanmıştır. Ek olarak, en ilgili yayınların çıktıları derlenmiştir. Çalışmanın ikinci kısmı ise yakınsayan sanayilerin sınırlamalarından ve yakınsamaya neden olan dışsallıklardan bağımsız bir şekilde sektörleri değerlendirmek için, “Sektörel Sorunlara Ar-Ge Temelli Çözümler” çalışmasına dayanmaktadır. Bahse konu çalışma, 2013-2014 yılları arasında TÜBİTAK Bilim, Teknoloji ve Yenilik Politikaları Dairesi Başkanlığı tarafından önceliklendirilen on beş sektörde Ar-Ge ile çözülebilecek sorunların belirlenmesine yönelik envanter oluşturması amaçlanmıştır (Saraçoğlu, 2014). Bu sektörler, Otomotiv, Makine-İmalat, BİT, Enerji, Gıda, Su, Sağlık, Havacılık ve Uzay, İnşaat, Kimya, Metal Sanayi ve Madencilik, Mobilya, Seramik, Tekstil ve Ulaştırma’dır. Bu şekilde, ayrı ayrı envanteri oluşturulan ve öncelikleri belirlenen sektörlerle, sektörler arası eşleme analiz yöntemi uygulanarak ayrı öncelikler üzerinden dahi yakınsama gösteren sektörler belirlenmiştir. Her iki kısmın sonuçları otomotiv ve BİT sektörlerinin tezin durum çalışmasında kullanılması ve CSIS yaklaşımının ana konseptinin formüle edilmesi açısından girdiler sunmuştur.

3. Adım “Sektörler Arası Yenilik Sistemi (CSIS) Yaklaşımı için bir Analiz Yöntemi Önerilmesi”dir. Bu adım “**Bölüm 4 - Sektörler Arası Dinamikler için Analiz Yöntemi Önerisi**” olarak sunulmuştur. Önceki adımlarla CSIS yaklaşımının ana unsurlarının belirlenmesiyle, IS'nin haritalanması ve yakınsamanın ölçülmesine ilişkin mevcut yöntemlerden de faydalanılarak uygun analiz yöntemi formüle edilmiş; ve ilgili boyutlar ve göstergeler tezin ana araştırma sorusuna uygun olarak belirlenmiştir. Analiz yöntemi bağlam ve yöntem olarak iki bölümde geliştirilmiştir. Ayrıca, analiz yöntemini geliştirmek için kullanılan her bir model arasındaki ilgili bağlantılar ve benzer yapısal bileşenler detaylı olarak sunulmuştur. Geliştirilen ve önerilen sektörler arası eşleme analiz yöntemi aşağıda özetlenmektedir.

Daha önce de belirtildiği üzere tezin analiz birimi sektörler olduğu için SIS yaklaşımına özellikle odaklanılmıştır. Bu nedenle, analiz yönteminin içeriği temel

olarak SIS yaklaşımının (Malerba, 2002a, 2004) ve Fonksiyonel Dinamikler (FD) Modelinin (Bergek vd., 2005, 2008) özellikleri ile yakınsama türleri arasındaki iki taraflı itme-çekme dinamiğini de gösteren talep odaklı yenilik politikaları incelenerek türetilmiştir. Bu tezde analiz yöntemi sektörler arası bir bakış açısı içereceğinden, yenilik sisteminin yapıtaşları dört boyut ve on üç gösterge olarak belirlenerek, sektörler arası eşleştirmesi mantığı geliştirilmiştir. Boyutlar ve göstergeler aşağıdaki gibidir:

- (1) İhtiyaçların Eşleştirmesi (mevzuatlar, stratejiler, iç pazar oluşumu, sektörel dinamiklerin ayrı olarak değerlendirilmesi (örnek çalışma: “Sektörel Sorunlara Ar-Ge Temelli Çözümler”), vb.),
- (2) Kapasite Eşleştirmesi (Ar-Ge harcamaları, bilimsel ve teknolojik kapasite vb.),
- (3) Stratejik Önem Eşleştirmesi (ekonomik ve sosyal etkiler, seçilen sektörlerin KET olması durumu vb.) ve,
- (4) Küresel Eğilimlerin Eşleştirmesi (dünya pazarlarının eğilimi ve ana aktörlerin stratejileri (ülkeler, uluslararası BTY politika kuruluşları, firmalar, vb.)).

Daha sonra, araştırma sorularına uygun olarak CSIS yaklaşımının bağlamını ve analiz yöntemini yakınsamaya yönelik daraltmak için, IS haritalama ve yakınsama ölçümü için mevcut yöntemler de kısaca gözden geçirilmiştir. Örneğin, Chang ve Chen (2004), ulusal, teknolojik/sektörel ve bölgesel IS yaklaşımları için IS haritalama yöntemlerini ağ oluşturma/kartopu, topluluk/üyelik ve kümelenme şeklinde üç yaklaşım olarak belirtmektedir. Chang ve Chen'e (2004) göre, IS'i haritalamak için bu üç yaklaşım birbirinden çok ayrılmamakla birlikte hepsinin zayıf yönleri de bulunmaktadır. Ağ yaklaşımı hem teknoloji tabanları hem de pazar tabanları açısından gayri resmi etkileşimlerin haritalanmasını göz ardı ederken; topluluk yaklaşımı, yenilik sistemlerindeki kurumsal etkileşimi çerçevelemek için gayri resmi bağlantılardan görüşler sağlamaktadır. Öte yandan, yenilik sistemlerinde teknoloji tabanları arasındaki karşılıklı bağımlılığın haritalandırılması için patent ve yayınların kullanılmasıyla kümelenme yaklaşımının avantajlı olduğu belirtilmektedir. Bununla

birlikte, patent ve yayın analizinin kullanılmasının tüm sistemik bağlantıları belirlemek için tatmin edici bir çözüm olmayacağı da tartışılmaktadır.

Yakınsama literatürüne bakıldığında ise yaygın ve tekrarlayan analiz yöntemlerinin kullanıldığı görülmektedir. Örneğin, Jeong vd. (2015) tüm yakınsama türleri için ölçüm yöntemlerini tartışmaktadır. Buna göre, bilim yakınsaması için literatürde ortak kelime analizi, ortak atıf analizi, ortak yazarlık analizi ve dergi konu kategorisi ortak sınıflandırma analizi gibi bilimsel yayınlara dayanan bibliyometrik analiz yöntemleri kullanılmaktadır. Bu yöntemlerin disiplinlerarası araştırmalar için de somut sonuçlar verdiği belirtilmektedir. Teknoloji yakınsaması için, çoğunlukla bir patentin teknolojik kategorilerinin (Uluslararası Patent Sınıflandırması-IPC) birlikte atıflanması veya ortak sınıflandırılması kullanılmaktadır. Ancak, kaynak olarak patentlerin kullanılması daha çok sınırlama içermektedir. WIPO, IPC'ye karşılık gelen teknoloji sınıflandırmasını gösteren beş sektör ve otuz beş alandan oluşan resmi bir “IPC-Teknoloji Uyum Tablosu” sunmaktadır. Ancak, bu tablo alt teknoloji alanlarını içermemektedir. Bu nedenle, patente dayalı bu yöntemlerin sadece makro düzeyde teknoloji yakınsamasının doğasını gösterdiği ve deneysel kaldığı vurgulanmaktadır. Patentlere dayalı ortak kelime analizi kullanan çalışmalar olsa da, teknolojik alanlarda genel olarak kabul edilebilir veriler sağladığı düşünülmemektedir (Curran ve Leker, 2011; Jeong vd., 2015). Ayrıca, sektörler arası dinamikler açısından teknoloji yakınsaması konusunda herhangi bir uygulama veya yöntem bulunmamaktadır.

Pazar yakınsaması ve sanayi yakınsaması, daha yeni araştırma alanları olduğundan, ölçüm yöntemleri de gelişmeye açık durumdadır (Curran vd. 2010; Curran ve Lecker, 2011). Pazar yakınsaması, ürünler için ortak ve ölçülebilir bir parametre sınıflandırması olmamakla birlikte basın bültenlerine dayalı ürün spesifikasyon analizi ile ölçülebilmektedir. Sanayi yakınsaması ölçümü için, sanayi sınıflandırması (Standart Sanayi Sınıflandırması-SIC, NACE veya ISIC) ve IPC'leri uyumlaştırarak (Fai ve von Tunzelmann, 2001; Karvonen vd., 2012; Karvonen ve Kässä, 2013) veya bir patent için SIC ve belirli anahtar kelimeleri eşleştirerek (Curran vd., 2010) göstergeler öneren çalışmalar vardır. Ortak sınıflandırma yönteminde, birden fazla

IPC'ye tahsis edilen patentlerin teknoloji yakınsaması sunduğu varsayılmaktadır. Ayrıca, bir patent heterojen sektörler gösteriyorsa, teknolojiye dayalı sektörler arası yakınsama gösterdiği varsayılmaktadır. Sanayi yakınsaması daha çok teknoloji yakınsaması ile ilişkilendirilmektedir. Teknoloji yakınsamasını değerlendirmek için de çoğunlukla yukarıda belirtilen patent türlerinin (yani yakınsayan patentlerin) toplam patent sayısına oranı kullanılmaktadır. Ancak, ortak sınıflandırma yöntemi, teknolojik alanların doğrudan belirlenmesine olanak sağlarken, bu çalışmaların yakınsama aşamalarını göz ardı ettiği belirtilmektedir.

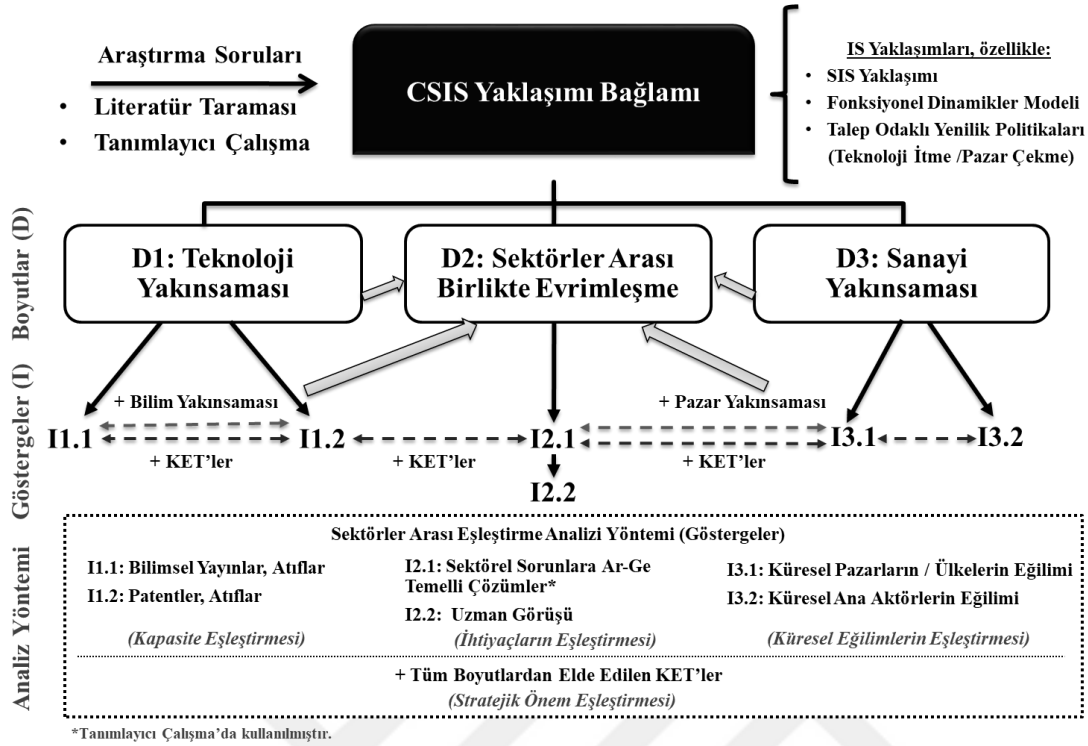
Belirtilen analiz yöntemleri kapsamlı bir şekilde teknolojik sınırların uygulanabilir ve yeterli sınıflandırmasına dayandığından, geliştirilmiş olan uyum tablolarının eksiklikleri bulunmaktadır. Bu nedenle, analiz yöntemini uygun anahtar kelime kümeleri ile yürütmek ve uyum tablolarıyla eşleştirmek için en azından belirli araştırma alanlarında ve/veya sektörlerde uzmanlık gerekmektedir.

Öte yandan, yakınsama türüne odaklanılarak belirli yöntemler kullanılırken, yakınsama türleri arasındaki etkileşimin sonuçları göz ardı edilmektedir. Ayrıca, çoklu, çapraz ve disiplinlerarası araştırmaları incelerken ortak kelime ve ortak atıf analizleri doğru olarak kabul edilmekte, ancak özellikle atıf kullanan yayın verilerinin sınırlamaları ve eksiklikleri göz ardı edilmektedir. Bu yöntemlerin yakınsama kavramıyla ilgili tatmin edici girişimlerle sonuçlandığı düşünülürken, IS yaklaşımlarıyla bütünleşmede veya iki veya daha fazla farklı baskın sektörü içeren sektörler arası yaklaşımları incelemek için yeterli bir yöntem sunmadığı gözlemlenmiştir. Bu nedenle, yukarıda belirtilen yöntemler, tezde önerilen analiz yönteminin tasarımına entegre edilerek CSIS yaklaşımı için geliştirilerek uyarlanmıştır. Dolayısıyla, bu tezin ana araştırma sorusunun amacına göre bağlam ve analiz yöntemi daraltıldıktan sonra, **analiz yönteminin ana boyutları literatür taramasında incelendiği gibi teknoloji yakınsaması, sektörler arası birlikte evrimleşme ve sanayi yakınsaması olarak belirlenmiştir.**

Öte yandan, sanayi yakınsamasının tüm yakınsama türlerinin etkileşimli ve yinelemeli bir itme-çekme mekanizması sonucu gerçekleştiği ve ayrıca tüm yakınsama türlerinin birbirleriyle yakın etkileşim ve etki içinde olduğu gözlemlendiğinden, bilim yakınsaması ve pazar yakınsaması analiz yönteminin organik boyutları olarak kabul edilmiştir.

Ayrıca, KET'lerin oluşumu ve etkisi sektörler arası dinamikler için önemli görüldüğünden ve yakınsama ile iki yönlü itme-çekme dinamiğinin bir sonucu olduğundan KET'ler de boyutlardan biri olarak belirlenmiştir. Ancak, KET'lerin belirlenmesinde önerilen yöntemdeki tüm boyut ve göstergelerin kullanılabileceği düşünüldüğünden ek göstergeler tanımlanmamış olup tüm boyutlara ilişkin analiz sonuçları değerlendirilmiştir. Son olarak, bilim ve teknoloji arasındaki yakınsama veya yakınsama sürecinin dinamikleri gibi hususlar da göz ardı edilmemiştir. Bu bakış açısıyla, söz konusu organik boyutlar, temel ve ölçülebilir boyutlar olarak analiz yöntemine entegre edilmiştir.

Dolayısıyla, bilim, teknoloji ve pazar yakınsamaları, ilgili nicel ve nicel yöntemler ve verilerle ayrı ayrı analiz edilmiştir. Buna göre altı gösterge belirlenmiş ve birden fazla sektörün sektörler arası bir bakış açısıyla analiz edilmesi amaçlandığından hepsi için **anahtar kelimelere dayalı eşleştirme yöntemi yani “Sektörler Arası Eşleştirme Analizi Yöntemi”** oluşturulmuş (Şekil H.1), önerilmiş ve “Durum Çalışması” ile de uygulanmıştır.



Not: Teorik Arka Planda (Bölüm 2) incelendiği gibi, Şekil'de gösterilen üç boyut bu tezin ana boyutları olarak kabul edilmekle birlikte, (+) işaretiyle gösterilen ve daraltma sürecinin sonucu olan organik boyutlar analiz yönteminde kullanılmıştır.

Şekil H.1. CSIS Yaklaşımına İlişkin Durum Çalışması için Önerilen Analiz Yöntemi

Organik boyutlar da entegre edildikten sonra **anahtar kelimelere dayalı “Sektörler Arası Eşleştirme Analizi Yöntemi”** aşağıdaki boyutları ve göstergeleri içerecek şekilde tasarlanmıştır (Şekil H.1, Şekil 4.2, Tablo 4.3, D: Boyut, I: Gösterge):

(1) **D1 “Teknoloji Yakınsaması” kapsamında; “Bilim Yakınsaması” D1.1 ve “Teknoloji Yakınsaması” D1.2** olarak kabul edilmektedir. **“Kapasite Eşleştirmesi”** ile ilgili olarak sırasıyla “Bilimsel Kapasite” ve “Teknolojik Kapasite” ile uyumludur. D1.1 için göstergeler bilimsel makaleler, atıflar, ortak atıflar (I1.1) ve D1.2 için patentler, patent atıfları ve patentlerin ortak atıfları (I1.2) olarak belirlenmiştir. Her ikisi için de nicel analiz yöntemleri kullanılmaktadır.

(2) **D2, “Sektörler Arası Birlikte Evrimleşme”**dir ve bu boyut bir bütün olarak **“İhtiyaçların Eşleştirilmesi”** ile uyumlu olarak değerlendirilmektedir. Uzman

görüşlerinin sektörler arası birlikte evrimleşmeyi analiz etmek ve KET'leri belirlemek için önem arz ettiği düşünülmektedir. Bu nedenle, nitel analiz yöntemlerinin bu boyut için daha uygun olduğu değerlendirilmektedir. Ayrıca, sektörler arası dinamikleri, özellikle birlikte evrimleşmeyi gözlemlemede, yakınsama etkisini dışarda tutacak şekilde sektörleri ayrı ayrı ele alarak incelemenin önemli olduğu değerlendirilmektedir. Hatırlanacağı gibi, bu ihtiyaca karşılık gelen bir çalışma, Tanımlayıcı çalışmanın (Bölüm 3.2) kısımların biri olarak zaten sunulmuştur. “Sektörel Sorunlara Ar-Ge Temelli Çözümler Çalışması”na dayalı sektörel dinamiklerin sektörler arası eşleştirme analizi yapılmıştır. Bu çalışma analiz yönteminin göstergelerden biri olarak kabul edilmekle birlikte (I2.1), Bölüm 3'te zaten kullanıldığı için, sonuçlar göz ardı edilmeden durum çalışması için tekrar kullanılmamıştır. Bu husustan hareketle, ikinci gösterge olarak “Uzman Değerlendirmesi” (I2.2) belirlenmiş ve sektörler arası eşleştirme analizi yöntemi kullanılarak alt teknoloji alanlarının önceliklendirilmesi, Delfi yöntemi ve sektörler arası perspektifte yakınsama türünün önceliklendirilmesini içeren yapılandırılmış bir anket (çevrim içi uzman katkı formu) hazırlanmıştır. I2.1'in daha önce bu tür bir çalışmanın yapılmadığı durumlarda uygulanması gerektiği ve “Uzman Değerlendirmesi” (I2.2) göstergesiyle entegre tek bir gösterge olarak uygulanabileceği düşünülmektedir.

(3) D3, “Sanayi Yakınsama”dır. Daha önce de açıklandığı gibi, sanayi yakınsaması sektörler arası dinamiklerin ve diğer yakınsama türlerinin bir sonucu olarak oluşmaktadır. Bu nedenle, organik boyutların entegrasyonundan sonra **“Pazar Yakınsaması” D3 olarak kabul edilmiştir.** Küresel piyasa eğilim analizi gibi ikincil verilere dayalı nicel analiz yöntemlerinin, bu boyuta daha uygun olduğu düşünülmektedir. Bu nedenle, bu boyutun iki göstergesi “Küresel Piyasaların/Ülkelerin Eğilimleri” (I3.1) ve “Küresel Baskın Aktörlerin Eğilimleri” (I3.2) şeklinde belirlenmiştir. Görüldüğü gibi bu boyut bir bütün olarak **“Küresel Eğilimlerin Eşleşmesi”** ile uyumlu olarak değerlendirilmektedir.

(4) **KET'ler**, organik boyutlardan biri olmasına rağmen, KET'ler yukarıda belirtilen tüm boyutlardan belirlenebileceği için başlı başına ayrı bir boyut olarak kabul edilmemiştir. Özellikle yakınsama gerçekleştiğinde, KET'ler hem itici güç hem de sektörler arası dinamiklerin sonucu olarak oluşmaktadır. Bu nedenle, ayrı göstergeler belirlenmiştir ve yukarıda belirtilen göstergelerin tümü KET'leri belirlemek için kullanılmaktadır. KET'ler **“Stratejik Önem Eşleştirme”** ile uyumlu olarak değerlendirilmektedir.

4. Adım "Durum Çalışması: CSIS Analiz Yöntemine Dayalı Otomotiv ve BİT Sektörlerinin Yakınsama ve Birlikte Evrimleşmesi"dir. Tanımlayıcı çalışmanın (Bölüm 3) sonuçlarından biri olarak, otomotiv ve BİT sektörleri, oluşturulan “sektörler arası eşleştirme analiz yöntemi”ni uygulamak için seçilmiştir. Bu adım nicel ve nitel analizleri içeren iki kısımdan oluşmaktadır ve **“Bölüm 5 - Durum Çalışması: Otomotiv ve BİT Sektörleri için Sektörler Arası Yenilik Sistemi Analizi”** olarak iki bölümde sunulmuştur; **"Bölüm 5.1 – Nicel Analiz"** ve **"Bölüm 5.2 - Nitel Analiz"**.

Otomotiv ve BİT sektörleri için öncelikle sektörel kapsamı (NACE Rev2) değerlendirilmiş ve ardından bir dizi bibliyometrik özütleme (ekstraksiyon) çalışması yapılarak alt teknoloji alanları ve anahtar kelimeleri belirlenmiştir. Ayrıca, en iyi gözlemi elde etmek için hem nicel (bibliyometrik ve eğilim analizleri) hem de nitel (uzman görüşleri için yapılandırılmış katkı formu) analizler formüle edilmiş, gerçekleştirilmiş ve değerlendirilmiştir. Bu tezin araştırma sorusu ile ilgili olarak birden fazla baskın sektörün yakınsama (özellikle teknoloji yakınsaması) temelinde birlikte evrimleşmesi incelenmiş ve sektörler arası yönleri analiz edilmiştir. Hem nicel hem de nitel yöntemler uygulanmıştır. Aşağıdaki alt adımlar, durum çalışmasının alt bölümlerini yansıtmaktadır:

Adım 4.1 “Nicel Analiz”dir ve **“Bölüm 5.1 - Nicel Analiz”** olarak, tüm yakınsama türlerinin sırasıyla ilgili eşleştirme analizi yöntemleri kullanılarak analiz edilmesi şeklinde birbirini takip eden üç bölümde sunulmaktadır. Tüm analizler küresel veriler

kullanılarak yapılmaktadır, ancak bu tezin Türkiye'de çalışılması nedeniyle, her bir analiz için varsa Türkiye verileri de Ek E'de sunulmuştur.

“Bölüm 5.1.1 - Bilimsel Yakınsama için Nicel Analiz” için, 2007-2017 yılları arasında otomotiv ve BİT sektörlerinde bilimsel yayınlar/atıf verileri kullanılarak bibliyometrik bir eşleştirme analizi yapılmıştır. SCOPUS Veritabanından çekilen veriler kullanılarak alt teknoloji alanlarından anahtar kelime eşleşmesine dayalı olarak bibliyometrik ortak kelime analizi yapılmıştır. Ek olarak, VOSviewer kullanılarak yazar anahtar kelimelerine ve atıflarına dayalı olarak birlikte sıklık ve toplam bağlantı gücü eşlemeleri yapılmıştır.

“Bölüm 5.1.2 - Teknoloji Yakınsaması için Nicel Analiz” için, otomotiv ve BİT sektörlerinde 2007-2017 yılları arasında patent/patent atıf verileri kullanılarak bir bibliyometrik eşleştirme analizi yapılmıştır. Derwent Veritabanından çekilen patent verileri kullanılarak alt teknoloji alanlarından anahtar kelime eşleşmesine dayalı olarak bibliyometrik ortak kelime analizi yapılmıştır. Ek olarak, VOSviewer kullanılarak patent anahtar kelimelerine ve geriye dönük atıflara dayalı olarak birlikte sıklık ve toplam bağlantı gücü eşlemeleri yapılmıştır.

“Bölüm 5.1.3 - Pazar Yakınsaması için Nicel Analiz” için, sektörler arası eşleştirme analizinde otomotiv ve BİT sektörlerindeki ana aktörlerin stratejileri kaynak olarak kullanılmış olup iki adımda küresel eğilim analizi yapılmıştır. Öncelikle, uluslararası kuruluşlara dayalı küresel pazar eğilimleri **“Bölüm 5.1.3.3 - Küresel Pazar Eğilimleri Bazında Sektörler Arası Eşleştirme Analizi”** olarak sunulmuştur. Bu kapsamda, OECD, MGI, Deloitte gibi uluslararası kuruluşların raporları incelenmiştir. Devamında, ilk adım olarak her iki sektörün baskın ülkeleri açısından sektörler arası ulusal stratejileri ve ilgili çalışmaları incelenmiştir ve **“5.1.3.4 - Belirlenen Ülkelere Göre Sektörler Arası Eşleştirme Analizi”** olarak sunulmuştur. İkinci adım olarak, her iki sektördeki baskın özel sektör aktörlerinin sektörler arası stratejilerine dayalı eğilimler incelenerek **“5.1.3.5 – Belirlenen Firmalara Göre Sektörler Arası Eşleştirme Analizi”** olarak sunulmuştur. Otomotiv ve BİT sektörleri için analiz etmek

üzere baskın ülke ve firmaların seçiminde, bilim ve teknoloji yakınsamasına ilişkin nicel analizlerin sonuçları ile ülkelerin ve firmaların küresel endekslere göre (Küresel Yenilik Endeksi, Küresel Rekabetçilik Endeksi, Küresel Yenilik 1000 Çalışması) Ar-Ge ve yenilik performansları kullanılmıştır. İncelenmek üzere belirlenen on baskın ülke; ABD, Çin, Almanya, Japonya, İngiltere, Güney Kore, Kanada, Fransa, Singapur ve Tayvan'dır. İncelenmek üzere belirlenen on baskın firma ise; Google, Microsoft, Apple, Siemens, General Motor, Continental, Ford Motor, Volkswagen, Toyota Motor ve Tesla'dır. Crunchbase Veritabanında firmaların sektörler arası yatırımları da incelenmiştir.

Otomotiv ve BİT sektörler arası yakınsama eğilimi, sektörler arası yaklaşımla değerlendirilmiş ve her iki sektör için baskın ülkeler için bir “Odaklanma Seviyesi (Level of Focus)” metriği türetilerek öne çıkan alt teknoloji alanları ve KET'ler ile haritalanmıştır. “Odaklanma Seviyesi” ülkelerin sektörler arası odaklanmasının stratejik boyutu değerlendirilerek puanlanmıştır. Örneğin, incelenen ülkelerin ulusal seviyede sektörler arası stratejik bir odaklanması varsa (sektörler arası Ar-Ge ve yenilik stratejisi, ulusal öncelikli alan olması, vb.) odaklanma seviyesi 10 olarak puanlanmıştır. Eğer bir ülkenin sektörler arası odaklanması genel bir destek mekanizmasından oluşuyorsa odaklanma seviyesi 5 olarak puanlanmıştır. Belirlenen ülkelerin sektörler arası eğilim analizinden belirlenen KET'ler, hem bilim hem de teknoloji yakınsaması için gerçekleştirilen nicel analizlerdeki en çok ilgili beş alt teknoloji alanıyla ilişkilendirilerek ağırlıklandırılmış bir ölçüm elde edilmiştir. Sonuç olarak, baskın ülkelere ve baskın özel sektör aktörlerine dayalı küresel eğilim analizleri, otomotiv ve BİT sektörler arası yakınsama, sektörler arası yakınsamanın yönü ve odak seviyesi öne çıkan alt teknoloji alanları ile haritalanmıştır.

Adım 4.2, “Nitel Analiz”dir ve “Bölüm 5.2 - Nitel Analiz” olarak sunulmuştur. Yukarıda açıklanan nicel analiz yöntemlerine ek olarak, sektörler arası dinamikler konusunda yetkin sektör uzmanlarının bakış açısını elde etmek için, Limesurvey çevrim içi anket sistemi üzerinden uzman katkı formu hazırlanarak uygulanmıştır. Uzman katkı formu, ikisi zorunlu olmak üzere üç ana bölümden oluşmaktadır. Birinci

bölümde sektörler arası dinamikler dikkate alınarak otomotiv ve BİT sektörlerinin alt teknoloji alanlarının önceliklendirilmesi istenmiştir (1-5 puan ile önceliklendirme tekniği). İkinci bölüm isteğe bağlı olarak uygulanmıştır ve sektörler arası dinamiklerin değerlendirilmesi için hedef ifadeler toplanmıştır (Delfi Tekniği). Üçüncü bölümde, otomotiv ve BİT sektörleri arasındaki sektörler arası etkileşimin birlikte evrimleşmesine etkisi açısından yakınsama türlerinin önceliklendirilmesi istenmiştir. Sektörlerin tek taraflı mı dönüştüğü, hangi tür yakınsamanın en fazla etkiye sahip olduğu vb. hususların dikkate alınması beklenmiştir (1-10 arası puanlama tekniği). Delfi Tekniği için Semantria kullanılarak önceliklendirilen KET'lerin anahtar kelime bulutu oluşturulmuştur. Öte yandan, daha ileri bir değerlendirme için Sankey diyagramları kullanarak otomotiv ve BİT sektörler arası yakınsaması önceliklendirilmiş KET'ler bazında gösterilmiştir.

5. Adım, durum çalışması olarak gerçekleştirilen nicel ve nitel analizlerin sonuçlarının değerlendirilmesini içermektedir ve her analiz bölümünde ayrıca sunulmuştur. **6. Adım**, "**Bölüm 6 - Sektörler Arası Yenilik Sisteminin (CSIS) Kavramsallaştırılması**" olarak sunulmaktadır. Tarama bulguları ve yapılan analizlerin sonuçları kullanılarak IS literatürüne bir katkı ve IS literatürüne tamamlayıcı olarak kavramsallaştırma çalışmasına girdi sağlamıştır. Son olarak, **7. Adım**, tezin araştırma sonuçlarını, tartışmaları ve politika önerilerini kapsayacak şekilde hazırlanmış ve "**Bölüm 7 - Sonuçlar**" olarak sunulmuştur.

Tezin Temel Bulguları ve Sektörler Arası Yenilik Sistemi (Cross-Sectoral Innovtion Systems – CSIS) Yaklaşımı Kavramı

Literatür taraması ve tanımlayıcı çalışmadan, yakınsamanın, özellikle teknoloji yakınsamasının, ilgili IS'nin sektörlerin temellerini ve dinamiklerini dönüştürdüğü görülmektedir. Hızla ilerleyen bir eğilim olan teknoloji yakınsaması, ilgili IS'nin dinamiklerini dönüştürme eşiğini azaltırken, yeni ekonomi ve IS için itici güç haline gelmektedir. IS literatüründe, yakınsama ve yakınsamanın yıkıcı etkileri önemli olarak görülmektedir, ancak teknolojik evrim analizi yoluyla teknolojik değişime

odaklanılmaktadır ve yakınsama ve etkileri ilgili IS'nin iç dinamiği olarak kabul edilmekte ve o kapsamda analiz edilmektedir. Ayrıca, sektörlerin birden fazla teknolojiden oluştuğu varsayılırken, sektörler birbirine bağımlı ve tamamlayıcı olarak kabul edilmektedir. Bu bağlamda, sektörlerin kurumsal ortamlarıyla birlikte geliştiği kabul edilmektedir. Öte yandan, sektörlerin yenilik performansı açısından da destekleyici/ilgili sektörlerin varlığından etkilendiği belirtilmektedir. Örneğin, SIS yaklaşımı, baskın sektör ile ilgili/destekleyici sektör arasındaki bağlantılar ve tamamlayıcılıklar açısından sektörlerdeki heterojenliğin kilit bir unsur olduğunu öne sürmektedir.

Bu nedenle, teknoloji yakınsaması ve bunun sektörler ve yenilik sistemleri üzerindeki etkileri, hem kavramsal hem de yöntemsel açıdan iyileştirme için kritik konulardan biri olarak ortaya çıkmaktadır. Sektörler arası dinamikleri daha iyi anlamak için, sektörel sınırları tanımlayan bağlantıların ve tamamlayıcılıkların birden fazla baskın sektör perspektifinden ele alındığı bir yaklaşıma doğru iyileştirme ihtiyacı vardır. Ayrıca, IS literatürü ve yakınsama literatürünün, KET'lerin ve sektörlerin dönüşümünü ve yakınsamanın yıkıcı etkisinin varlığında dinamiklerini gözlemlemek için bütünlük olmadığı görülmektedir. Dolayısıyla, "sanayi" kavramının kendisi hızla değişirken ve “yenilik” kavramı birden fazla baskın sektörün yoğun etkileşiminin bir sonucu olarak kabul edilirken, mevcut IS yaklaşımlarının bu dinamikleri gözlemlemek ve daha iyi anlamak açısından geliştirmeye açık kaldığı değerlendirilmiştir.

Ayrıca, talep odaklı yenilik politikaları incelendiğinde, yakınsamada etkileşimli bir itme-çekme dinamiği olduğu gözlemlenmektedir. Bu etkileşimli dinamik sonucunda, yakınsama ve talep odaklı yenilik politikalarına dayalı sektörler arası yaklaşımların KET'lerin oluşmasına yol açtığı görülmüştür. KET'lerin oluşması ise yakınsamayı tetikleemkte ve nihayetinde sektörel sınırların bulanıklaşmasına, yeni sektörlerin oluşumuna ve yeni sektörel dinamiklerin oluşumuna sebep olmaktadır. İki taraflı ve etkileşimli bir ilişki olarak, bir teknoloji itme dinamiği, tamamen yeni pazarlara ve toplumsal gelişmelere yol açabilecek radikal yenilikler üretmektedir. Yeniliklere yol açan pazar çekme dinamikleri, belirli pazar ihtiyaçlarına yanıt olarak en baştan

oluşturulmaktadır. Bununla birlikte KET'lerin etkisi, ekonomiyi ve platforma dayalı, isteğe bağlı mobilite hizmetlerini paylaşma gibi pazardaki radikal yenilik potansiyelini artırmaktadır.

Yukarıda bahsedilen bulgular, birden fazla baskın sektörün etkileşimini analiz etmek için **Sektörler Arası Yenilik Sistemi (CSIS)** yaklaşımına ihtiyaç duyulduğunu düşündürmektedir. CSIS yaklaşımına yönelik gözlemlenen ihtiyaç için hem kavramsal hem de analitik çalışmalar yürütülmüştür. Birden fazla baskın sektörün alt teknoloji alanlarını ve/veya anahtar kelimelerini eşleştirmeye dayalı bir analiz yöntemi, yani **“sektörler arası eşleştirme analizi yöntemi”** geliştirilmiş ve önerilmiştir. Tanımlayıcı çalışmanın bulguları aynı zamanda durum çalışması için sektör seçiminde girdi olarak kullanılmış ve “sektörler arası eşleştirme analizi yöntemi” otomotiv ve BİT sektörleri için durum çalışmasında uygulanmıştır. Birlikte evrimleşme bakış açısıyla sektörler arası yakınsamayı ölçmek için hem nicel (yayın ve patent verilerine dayalı bibliyometrik analiz, küresel pazar ikincil verileri) hem de nitel (çevrim içi yapılandırılmış uzman katkı formu aracılığıyla uzman değerlendirmesi) yöntemler uygulanmıştır.

Durum çalışmasının temel bulguları, otomotiv ve BİT sektörlerinin, yeni bir sektör oluşturma sürecinde teknoloji yakınsamasına dayalı (bilim ve pazar yakınsamalarıyla etkileşimli olarak) birlikte evrimleştiğini ve dönüştüğünü göstermektedir. Öte yandan, yeni bir sektörün temellerini oluşturan (teknoloji ve pazar yakınsaması yoluyla) veya yeni bir sektörün kendisi haline gelen KET'ler de belirlenmiştir (örneğin, EHV'ler, CAV'ler, otonom araçlar, siber-fiziksel sistemler, yapay zekâ destekli otomotiv gömülü sistemler, araç yazılımı, araç içi iletişim teknolojileri ve uygulamaları, nesnelerin interneti (araçların interneti ve her şeyin interneti), akıllı / akıllı hareketlilik vb.). Bulgular, gelecekte OTO-BİT (AUTO-ICT) olarak yepyeni bir sektörün ortaya çıkmasının muhtemel olduğunu göstermektedir. Özellikle sektörlerin dinamikleri açısından (organizasyon yapıları, bilgi tabanı, teknoloji tabanı, pazar tabanı, iş modelleri, pazar oluşumu, disiplinlerarası alanlar, iş gücü, altyapılar, vb.) incelenen baskın sektörler arasında köklü bir değişim gözlemlenmiştir. Bu baskın sektörlerin,

özellikle yakınsamanın yıkıcı etkileri varlığında, mevcut SIS yaklaşımının önerdiği gibi ilgili/destekleyici sektörler olarak hareket etmediği açık olarak gözlemlenmiştir. İlgili baskın sektörlerin baskın aktörleri ve onların bilgi, teknoloji ve pazar tabanları, farklı baskın sektörlerle doğru kaymaktadır.

Ayrıca, SIS dinamiklerinde dikey entegrasyondan sektörler arası yatay entegrasyona doğru bir kayma, ortaya çıkan bir diğer önemli bulgudur. Durum çalışmasında otomotiv ve BİT sektörlerinin etkileşimine odaklanırken, diğer sektörlerle ilişkin yakınsamaya ve birlikte evrimleşmeye yönelik gözlemler de elde edilmiştir. Özellikle, enerji sektörü (enerji depolama ve alternatif yakıtlar, pil teknolojileri, e-mobilite, araçtan şebekeye iletişim (V2G), akıllı şehirler konseptiyle ve akıllı binalar ile entegrasyon, vb.), gelişmiş malzemeler (hafif araçlar, gelişmiş pil malzemeleri, vb.), gelişmiş imalat (3B yazıcılar, dijital ikiz, Endüstri 4.0 ile entegrasyon, vb.) ve hizmet sektörleri (dijital iş modelleri, paylaşım ekonomisi, hizmet olarak iş, hizmet olarak altyapı, blokzincir ile entegrasyon, vb.). Ayrıca, durum çalışmasının önemli bir sonucu da gözlemlenen tüm kaymalar ve yakınsamaların iki taraflı birlikte evrimleşme olduğunu göstermesidir. İki sektör de tüm yakınsama türleri açısından (teknoloji yakınsaması en etkili olacak şekilde) birlikte evrimleşmekte ve birbirlerinin dönüşümünü etkilemektedir.

Bu tezde, IS bakış açısı ile entegre edilmiş yakınsama eğilimini analiz etmek için önerilen yöntem kullanılmaktadır. Durum çalışmasından elde edilen bulgularla, CSIS yaklaşımının çerçevesi geliştirmeye açık yönleriyle birlikte mevcut IS yaklaşımlarını tamamlayıcı olarak önerilmektedir.

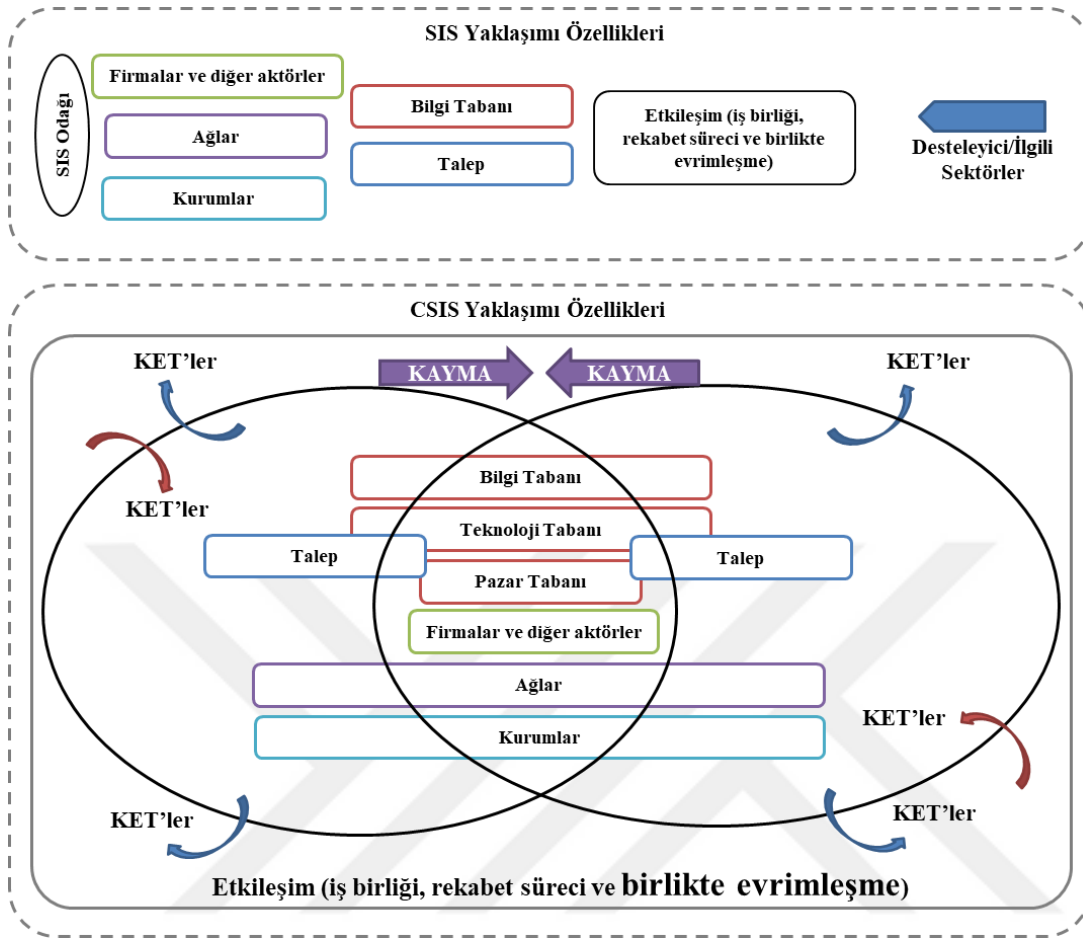
Bir kavram olarak CSIS yaklaşımı, birden fazla baskın sektör içinde birbirine yakınsayan ve ulusal, sektörel, bölgesel ve hatta daha geniş küresel yenilik sistemlerinde benzer bileşenleri değiştirebilen sektörler arası, karşılıklı bağımlı ve birlikte evrimleşme etkileşimlerini incelemeyi amaçlamaktadır. CSIS yaklaşımı, yakınsamadan etkilenen birden fazla baskın sektörün, yenilik sürecine ortaklaşa katkıda bulunan ve hatta yeni sektörlerin oluşmasına neden olan

sektörler arası farklı kurumların etkileşimlerini gözlemlemek için kullanılan bir çerçeve olarak tanımlanabilir.

Farklı sektörlerin incelenmesinde farklı sonuçlar elde edileceği göz önünde bulundurulmakla birlikte bu tezde gerçekleştirilen çalışmalar neticesindeki bulgulara dayalı CSIS yaklaşımı Şekil H.2 ve Şekil H.3 olarak sunulmaktadır.

Şekil H.2’de tek bir sektörü odağına alan ve diğer sektörleri destekleyici/ilgili sektör olarak gören SIS yaklaşımına tamamlayıcı olarak birbirine yakınsayan (kayma gösteren) iki ve daha fazla sektör için CSIS yaklaşımının özellikleri karşılaştırmalı olarak verilmektedir.

Şekil H.3’te ise CSIS yaklaşımının çerçevesi çizilmektedir. Sırasıyla CSIS yaklaşımının temel etmenleri, sektörler arası yakınsama neticesinde yeni sektörlerin, yeni ekonomi modellerinin oluşumu ile yenilik sistemlerinde değişiklikler ve sektörler arası yaklaşıma yönelik engeller sunulmaktadır. Sektörlerin sınırları bulanıklaşıp yok oldukça ilgili yenilik sistemlerinin de sınırları yok olmaktadır. Yenilik sistemlerinde yakınsamanın oluşturduğu kaymalara bağlı olarak bilgi, teknoloji ya da pazar tabanlarının değişimleri, ek olarak heterojen ya da homojen özellikler göstermesi (özellikle pazar tabanı açısından gözlemlenmiştir), yenilik döngülerinin karmaşıklaşması gibi değişiklikler oluşmaktadır. Sektörler arası birlikte evrimleşmenin de etkisi olarak sektörlerin bilinen dinamikleri de farklılaşmaktadır. Örneğin, pazar oluşumunu da yakından etkileyen standartlara, dijital iş modellerine daha bağımlı olduğu bilinen BİT sektörünün otomotiv ile yakınsamasıyla standardizasyon gereksinimleri, yeni iş modelleri, otomotiv sektörünün temel dinamiği haline gelmektedir.



Şekil H.2. SIS ve CSIS Yaklaşımlarının Özelliklerinin Karşılaştırılması



Şekil H.3. CSIS Yaklaşımının Kavramlaştırılması

Tezin Temel Politika Uygulama Önerileri

Bu tezin temel bulgularına uygun olarak, aşağıda sunulan üç politika uygulama önerisine yer verilmektedir. Bu politika çıkarımları, Şekil H.3'te sunulan CSIS yaklaşımı için karşılaşılan engellerle ilişkilendirilmiştir.

Politika Uygulaması 1: Sektörler Arası Yaklaşımlar için İş Birliğine Dayalı Yenilik Mekanizmalarının Geliştirilmesi

Durum çalışmasının temel bulgularından biri olarak, ulusal ve uluslararası sektörler arası iş birliklerinin ve platformların sektörlerin sınırlarını bulanıklaştırırken sektörlerdeki aktörlerin yapılarının da hızlı bir şekilde değişmesinde etkili olduğu görülmüştür. Bu nedenle, özellikle sektörlerin dönüşüm sürecinde ve yeni sektörlerin oluşumunda veri tabanlı iş modelleri büyük bir rol oynadığı için, KET'lerin özümsemesi ve verilere erişim çok önemlidir. Sektörlerin aktörlerinin teknoloji yakınsaması yoluyla üretilen yenilik ve büyüme fırsatlarından yararlanmasını sağlayacak politika önlemlerine halihazırda ihtiyaç duyulmaktadır. Durum çalışmasından sektörler arası iş birliklerine örnekler olarak, bulut ürünü Microsoft Azure'u kullanan ve otomotiv sektörünün küresel baskın aktörlerini içeren Microsoft'un "Bağlantılı Araç Platformu"; veya bağlantılı araçlar oluşturmak için küresel otomobil üreticileri, satış sonrası pazar ve teknolojiye hakim aktörlerin oluşturduğu küresel bir ortaklık olan "Google Open Automotive Cross-Sectoral Alliance"; veya elektronik kontrol sistemi ve araç içi ağı standardizasyonu ve ortak kullanımı ile güvenilirliği sağlamak için kurulan, hem otomotiv hem de BİT küresel baskın aktörlerinin ortaklığını içeren "Japonya Otomotiv Yazılım Platformu ve Mimarisi (JASPAR)" verilebilir. Bu iş birliklerinde sadece baskın aktörler değil, niş KET geliştiricileri de yer almaktadır. Ortaklıklar yerine doğrudan uluslararası sektörler arası iş birlikleri de çok yaygındır. Örneğin, otomotiv sektöründe baskın bir aktör olarak Almanya, otomotiv sektörü kapasitesini geliştirmek ve BİT sektör altyapısı ile birleştirmek için BİT sektöründe baskın aktör olan Tayvan ile uluslararası iş birliği yapmıştır.

Yukarıda belirtilen örnekler, sektörler arası perspektifte gerekli iş birlikçi ekosistemi ve baskın aktörlerin elde ettiği faydaları betimlemektedir. Bu kapsamda, farklı sektörlerden ana sektör ve alt sektör kuruluşlarının etkili olduğu karma iş birliklerini desteklemek için konsorsiyum destek mekanizmaları önemli görülmektedir (kamu araştırma kurumları arasındaki ortaklıklar, özel sektörün araştırma ihtiyaçlarına göre proje geliştirmek için sektörler arası mükemmeliyet merkezleri ve çoklu/çapraz/disiplinlerarası araştırma alanlarında eğitim programları). Bu bağlamda, Türkiye'de son dönemde geliştirilen konsorsiyum destekleri olumlu gelişmeler olarak değerlendirilmektedir (örneğin, Sanayi ve Teknoloji Bakanlığı Teknoloji Odaklı Sanayi Hamlesi Programı, TÜBİTAK Yüksek Teknoloji Platform Çağruları ve SAYEM Programı) ve sektörler arası yaklaşımları daha fazla desteklemek için geliştirilebilecekleri düşünülmektedir.

Yakınsayan teknolojiler geliştirmek için firmaları/araştırma enstitülerini güçlendirmek de önem arz etmektedir. KET'ler, yakınsayan teknoloji yenilik süreci ve sektörler arası yakınsama için kilit rol oynamaktadır. Bu bağlamda, firmalar/araştırma enstitüleri, KET'lerin ve bunların yakınsama etkilerinin farkındalığı aşamasından, onları bir yenilik sürecinde ve ticari amaçlarla aktif olarak kullanma aşamasına kadar danışmanlığa ihtiyaç duymaktadırlar. Bu bağlamda, finansal kaynaklara, en son teknolojiye sahip altyapılara ve yüksek nitelikli uzmanlıklara erişimi teşvik etmek çok önemli olmakla birlikte, iş birlikçi ekosistemin geliştirilmesi de desteklenmelidir. Bu bağlamda, arayüz kuruluşlar ve alanlar sektörler arası iş birliği ve birlikte geliştirme için desteklenirken sektörler arası ortaklıklar geliştirmek için de eşleştirme mekanizması geliştirilebilir. Özellikle, sektörler arası iş birlikleri için birlikte geliştirme öne çıkmaktadır. Çünkü sektörler arası yaklaşımlar, birden fazla baskın sektörden farklı aktörleri de ana aktörler olarak içermektedir. Buna örnek olarak başta son kullanıcılar ve üreten tüketiciler verilebilir. Birlikte geliştirmeyi ve sektörler arası iş birliğini teşvik edecek diğer mekanizma örnekleri, sektörler arası kümeler, ağlar, platformlar, iş birliğine dayalı başlangıç firmaları hızlandırıcıları ve yaşayan laboratuvarlar (living labs) olarak verilebilir.

Politika Uygulaması 2: Çoklu, Çapraz ve Disiplinlerarası Alanlarda Araştırma, Ar-Ge ve Test Altyapıları için Destek

Yukarıda verilen Politika Uygulaması 2'yle de ilişkili olarak, sektörler arası yaklaşımlarda karşılaşılan bir diğer engel, sektörler arası projelerin yanı sıra çoklu, çapraz ve disiplinlerarası alanlar için finansman eksikliğidir. CSIS yaklaşımı birden fazla baskın sektörün birden fazla KET ile yakınsamasını dikkate aldığından, çoklu, çapraz ve disiplinlerarası alanlarda araştırma çok önemlidir. Bu bağlamda, bir örnek, Almanya Fraunhofer Enstitüsü'nün altındaki on sekiz araştırma enstitüsü (Üretim Mühendisliği ve Otomasyon, Üretim Teknolojisi ve İleri Malzemeler, Çevre, Güvenlik ve Enerji Teknolojileri vb.) tarafından başlatılan OTO-BİT sektörler arası iş birliği girişimi (AutoMobil Üretim İş Birliği) olarak verilebilir. Bu girişimde, yeni nesil araçların üretilmesi için çoklu, çapraz ve disiplinlerarası araştırmalar desteklenmektedir. Bir başka örnek, BİT tabanlı bir otomotiv sektörü oluşturmak ve OTO-BİT sektörünü yaratmak için kurulan Kanada (BİT Tabanlı) Otomobil Mükemmeliyet Merkezi'dir (Auto21). Auto21 Kanada Mükemmeliyet Merkezleri Ağ Oluşturma Sekreteryası tarafından finanse edilmektedir. Auto21, kırk altı üniversite, iki yüz araştırmacı ve yüz yirmi kamu-özel sektör ortaklığından oluşmaktadır. Ar-Ge, özel sektör ihtiyaçları doğrultusunda disiplinlerarası alanlarda gerçekleştirilmekte ve Ar-Ge çıktıları kamu-özel sektör iş birliğinde ticarileştirilmektedir.

Öte yandan, ilgili proje çağrılarının ve geliştirilecek teknoloji yol haritalarının, sektörler arası perspektifi, ilgili KET'leri ve çoklu, çapraz ve disiplinlerarası alanları yansıtması önem arz etmektedir. Özellikle yeni sektörler oluşturma sürecinde olan KET'ler analiz edilmeli ve daha sonra teknoloji yol haritası çalışmaları ve proje çağrıları için ayrıca değerlendirilmelidir. Durum çalışmasının bulgularından, OTO-BİT sektörü durumunda bağlantılı ve otonom araçlar, otonom araçlar, siber-fiziksel sistemler yeni sektörler oluşturan KET'lere örnek olarak verilebilir. Örneğin, ülkemizde proje çağrı planları yöntemleri değişirken, çağrı başlığı ve içeriği sektörler arası olsa da genel olarak hâlâ sektörel bazda hazırlanmaktadır. Sektörler arası alanlar, sektörler arası dikey ve yatay entegre organizasyonlar anlamına gelir. Bu nedenle,

sektörler arası proje çağrılarını için çok organizasyonlu bir yaklaşım benimsenmelidir. Üstelik Türkiye dahil birçok ülkede çift kullanım (dual use) ve sektörler arası kullanım için alt teknolojiler için proje çağrılarını bulunmaktadır; ancak bu çağrılarının ve çağrı sonuçlarının (Ar-Ge ve teknolojiler) diğer sektörlerdeki yansımaları da çok önemlidir. Desteklenen alanların sektörler arası yönleri ve çağrılar sonucunda üretilen çıktılar dikkate alınmalıdır. Bu bağlamda, KET'lerin hem çift kullanım olanakları hem de ticarileştirilmesi üzerinde çalışmak üzere çoklu yapıları karar organları olarak “Sektörler Arası Danışma Kurulları” kurulabilir.

Ayrıca, test altyapıları da sektörler arası yaklaşımlarda, özellikle dijital dönüşüm açısından çok önemlidir. Birçok ülke, disiplinlerarası araştırma merkezlerinin kapasitesini güçlendirirken test altyapılarının geliştirilmesini de desteklemektedir. Örnek olarak, Bristol'daki UK Digital Catapult 5G test yatağı veya sürücüsüz araç testleri için kullanılan Bağlantılı ve Otonom Araçlar Merkezi olarak verilebilir. Bu bağlamda, Türkiye'de de son zamanlarda ilgili altyapılar kuruluyorken, devamlılık açısından test altyapılarını desteklemeye yönelik özel bir mekanizmanın olmaması ve ilgili altyapılara erişim koşullarının iyileştirilmesi geliştirmeye açık bir husus olarak görülmektedir.

Politika Uygulaması 3: İleriye Yönelik (Pro-Aktif) Sektörler Arası Düzenlemeler ve Standardizasyon Süreci İhtiyacı

Tezin bir diğer önemli çıktısı da, teknoloji yakınsamasından etkilenen sektörler arası yaklaşımlarda talep odaklı yenilik politikalarının kritik rolüdür. Örnek olarak, otomotiv sektöründe vergi teşvik indirimleri ve BİT sektöründe standardizasyon politikaları vurgulanabilir. Standartların ve standardizasyon süreçlerinin tetiklediği teknolojiye dayalı yenilik sürecinin, pazar oluşumuna ve yeni sektörlerin ortaya çıkmasına yansıdığı görülmektedir. Daha da önemlisi, sektörler arası yaklaşımlar söz konusu olduğunda, baskın sektörlerin dinamikleri birbirlerinin dinamiklerine yansımakta ve bu da birlikte evrimleşme ekosistemini yaratmaktadır. Örneğin, durum çalışmasının temel bulgularından biri, yalnızca BİT sektörünün otomotiv sektörünü

dönüştürmekle kalmayıp aynı zamanda birlikte evrimleştiğini ve bir OTO-BİT sektörünün de ortaya çıktığını göstermektedir. İncelenen ülkeler için de öncelikli sektörler olan baskın sektörlerin ayrı pazarları üst yapının (stratejiler, politikalar, kurumlar, düzenlemeler, standartlar, destekler, hedef odaklı girişimler, ortaklıklar, ulusal/uluslararası sektörler arası iş birlikleri, vb.) etkisiyle yakınsamaktadır. Sonuç olarak yapay zekâ, makine öğrenmesi, büyük very teknolojileri gibi KET'lerin de etkisiyle yeni pazarlar (ve sektörler) oluşmaktadır. Örneğin, elektrikli ve hibrit araçlar (elektro-mobilite), bağlantılı ve otonom araçlar (CAV'ler), akıllı mobilite vb. Sonuç olarak, 2030'lu yıllarda özellikle BİT sektörü açısından sektörler arası yatay entegrasyon olması beklenmektedir. Bu değişiklikler, ileriye yönelik sektörler arası düzenlemeler ve KET'ler için standardizasyon ile yanıtlanması gereken ulusal yenilik sistemleri ve sektörel yenilik sistemleri (NIS ve SIS) dinamiklerinde hızlı iyileştirme gereksinimlerini tetiklemektedir.

Ayrıca, ilgili NIS ve SIS'in dönüşümü için müşteri taleplerindeki, yönetmeliklerdeki ve standartlardaki değişiklikler de önemli faktörler olarak karşımıza çıkmaktadır. Sektörler arası yaklaşımlarda yasal düzenlemelerin ürünler arası ve platformlar arası lisanslamayı vb. esas alması gerektiği belirtilmektedir. Yakınsamanın pazar oluşumuna etkileri çok hızlı gelişmekte ve kamu politikasının ve yasal çerçevenin yeterliliği ve istikrârı genellikle bu hıza yetişmekte yetersiz kalmaktadır. Örneğin, durum çalışmasında incelenen firmaların, gelişmekte olan OTO-BİT sektörünün öncüleri olmanın zorluklarını ele aldıkları gözlemlenirken, aynı zamanda pazar oluşumu için standardizasyonlar tasarladıkları, bu nedenle küresel rekabet ve tescilli değer zinciri yarattıkları gözlemlenmiştir.

Gelecek Çalışmalar ve Ek Açıklamalar

Teknoloji yakınsaması sektörlerin sınırlarının bulanıklaşmasına neden olmakta, sektörlerin tanımlarını değiştirmekte ve KET'lere dayalı olarak yeni sektörlerin oluşmasını tetiklemektedir. Benzer şekilde, yenilik sistemlerinin sınırları da bulanıklaşmaktadır. Bu kapsamda, politika yapıcılar ortaya çıkan engelleri ortadan

kaldırmak için önlemler geliştirmeye yönelik yaptığı analizlerde sektörler arası dinamikleri analiz etme yöntemlerine yer vermelidir. Sektörler arası yaklaşımların önündeki en önemli engel, farkındalık ve odaklanma eksikliğidir. Alt teknoloji alanlarına ve anahtar kelimelere dayalı sektörler arası eşleştirme analizi yöntemi, bu tezde uygulandığı üzere etkili bir araç olarak düşünülmektedir. Daha ileri analizler, bir ülkede (ulusal-bölgesel) ikiden fazla baskın sektörü karşılaştırmak veya kendi bağlamlarında gelişmiş ve gelişmekte olan ülkeleri (uluslararası) karşılaştırmak gibi endeks çalışmalarını içerebilir. Önerilen analiz yöntemi, yakınsama ve yenilik sistemleri için potansiyellerin belirlenmesi için de kullanılabilir. Böylece yeni yenilik sistemi için yakınsamaya dayalı tedbirlerin uygulanması incelenebilir. Ayrıca, ikiden fazla baskın sektörü analiz etmek için uygulanabilir olması beklenmektedir. İkiden fazla baskın sektörün analiz edilmesi durumunda, bu tezde patentlere dayalı teknoloji yakınsamasının bibliyometrik analizi için uygulanan yöntemle benzer şekilde, kullanılan kaynaklara ve veritabanlarına bağlı olarak sektörel teknik özelliklerin tanımlanması ve/veya farklı kodlamanın oluşturulmasının gerekli olacağı düşünülmektedir.

Öte yandan, veritabanlarına ve kaynaklara göre değişen sıkıntılar ile veriye erişim sıkıntıları daha kapsamlı analizlerin yapılmasını zorlaştırmaktadır. Buna bağlı olarak, politika yapıcılar için sektörler arası verilerin eksikliği bir başka engel olarak vurgulanabilir. Ayrıca farklı boyutlara odaklanarak, örneğin rekabet boyutu, önerilen analiz yöntemi politika yapıcılarının uygulamasına yönelik daha da geliştirilebilir. Belirli alt teknoloji alanlarını ve anahtar kelimeleri belirleyerek sektörler arası verileri doğrudan çekmenin yolu bulunmamaktadır.

Aynı durum disiplinlerarası veriler için de geçerlidir. Mevcut durumda disiplinlerarası dergilerde yayımlanmış kaynaklara ilişkin veriler sunulmaktadır ve birçok sınırlama göz ardı edilerek disiplinlerarası alanlara yönelik ortak kelime ve ortak atıf analizleri doğru olarak kabul edilmektedir. Bu bağlamda, disiplinlerarası ve sektörler arası verilerin doğrudan çekilmesini sağlayan veri arayüzlerinin iyileştirilmesinin çok önemli olduğu düşünülmektedir. Ancak, ilgili kurumlar/kuruluşlar tarafından sektörler

arası verilerin belirlenmesi ve toplanmasına yönelik bir girişim olmadığından, doğrudan yollardan biri, atıfları sektörler arası bakış açısıyla analiz etmeye yönelik arayüzlerin geliştirilmesi olabilir. Örneğin, sınırlamalar bulunsa da, patent veri arayüzleri hem ileriye hem de geriye dönük atıf verilerini sağlarken, bilimsel yayın veri arayüzleri sadece atıflanan verileri sağlamaktadır. Bilimsel yayın veri arayüzlerinin de aynı sisteme sahip olması çok faydalı olacaktır. Ayrıca, hem bilimsel yayınlar hem de patentler için atıflayanın alanlarının belirlenmesine yönelik tekniklerin geliştirilmesi de önerilmektedir. Ek olarak, bu tezde uygulanan yöntem geliştirilirken webometrik, sektörler arası yatırım analizleri gibi teknikler de düşünülmüştür. Ancak, veriye erişim sıkıntıları olması nedeniyle sınırlı bir şekilde uygulanabilmiştir. İleri analizlerde yenilikçi tekniklerin entegre edilmesi ve geliştirilmesinde fayda görülmektedir. Ayrıca, firmalar da benzer veri sıkıntıları ve veri erişim engelleriyle karşı karşıya kalmaktadır. Veriye erişim sıkıntıları, özellikle yerli üreticiler ve KOBİ'ler için KET'lerin benimsenmesi ve sektörler arası dinamikler açısından rekabet koşullarında dezavantajlar yaratmaktadır.

Öte yandan, bu tezdeki CSIS yaklaşımının kavramsallaştırılmasının önerdiği gibi, küresel ve/veya ulusal acil durumlar da sektörler arası dinamikler için engeller olarak ortaya çıkabilmektedir. OECD 2020 çalışması, yaşanan küresel salgının, Ar-Ge yoğunluğu açısından farklılık gösteren bazı sektörler için sektörler arasında talepte azalmaya yol açtığını göstermektedir. Ar-Ge yoğun faaliyetler içeren ve küresel tedarik zincirlerine sahip imalat sektörlerinde (örn. otomotiv, elektronik) bu tür ürünlere olan talep kriz dönemlerinde yavaşladığı için daha fazla etkilendiği belirtilmektedir. Aynı çalışmada Nisan 2020 verileri gıda, dijital sağlık ve siber güvenlik alanlarındaki firmaların 2018/19 ortalamalarına göre daha fazla risk sermayesi aldığını göstermektedir; ve farklı yakınsayan talepler bulunmaktadır. Büyük imalat firmaları, örn. otomotiv, vantilatör, solunum cihazı, mask vb. acil ihtiyaca yönelik tıbbi ekipmanı üretmek için üretim hatlarını düzenlemişlerdir (Betti ve Heinzmann, 2020). Yakınsamanın etkisiyle sektörler arası dönüşümde olan sektörler, acil durumlarda diğer sektörlerle iyi entegre olabilmıştır. Yenilik sistemlerinde sektörler arası birlikte evrimleşme tetiklenmiştir. Desteklerde esneklikler getirmek, çift

kullanımı desteklemek, disiplinlerarası araştırma, iş birliği ve birlikte geliştirmeye dayalı ekosistemi teşvik etmek önem arz etmektedir.

Özetlemek gerekirse, bu tezin temel bulguları, yakınsama eğiliminin (özellikle teknoloji yakınsaması), sınırları ve dinamikleri dönüştürerek sektörler ve yenilik sistemleri için yıkıcı etkilere sahip olduğunu göstermektedir. Ayrıca, yakınsamanın etkisiyle oluşan KET'ler, ekonomilerin ve yenilik sistemlerinin temellerini değiştirme gücüne sahiptir. Sektörlerin sınırları bulanıklaşmakta, "sanayi" kavramı değişmekte, sektörler arası bilgi, teknoloji ve pazar tabanları yakınsamaktadır. Yakınsama ile sektörlerin birlikte evrimleşmesi, ve ortaya çıkan engeller, rekabetçi ortamı ve yenilik sistemlerini birlikte dönüştürmektedir. Bu kapsamda, bu tez, yenilik sistemleri yaklaşımları açısından teknoloji yakınsaması eğilimi ile sektörler arası dinamiklerin daha iyi anlaşılması için bir yöntem ve çerçeve ile sektörler arası dinamiklerin nasıl değiştiğini ve/veya dönüştüğünü, yeni sektörlerin ve/veya pazarların nasıl oluştuğunu ölçmek için yöntemler önermeyi amaçlamıştır.

Sonuç olarak, mevcut yenilik sistemleri yaklaşımlarından, özellikle de sektörel yenilik sistemleri ve mevcut analiz yöntemlerinden yararlanılarak, yakınsama süreci entegre edilmiş ve anahtar kelimelere dayalı **sektörler arası eşleştirme analizi yöntemi** önerilmiş; otomotiv ve BİT sektörlerine uygulanmıştır. Tezin temel bulguları değerlendirilerek, geliştirmeye açık yönleri olmakla birlikte **Sektörler Arası Yenilik Sistemi (CSIS)** yaklaşımının çerçevesi oluşturulmuş ve mevcut yenilik sistemleri yaklaşımlarına tamamlayıcı katkı olarak sunulmuştur.

I. 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 : SARAÇOĞLU

Adı / Name : DUYGU

Bölümü / Department : Bilim ve Teknoloji Politikası Çalışmaları / Science and Technology Policy Studies

TEZİN ADI / TITLE OF THE THESIS (İngilizce / English): THE EFFECT OF TECHNOLOGY CONVERGENCE ON CROSS-SECTORAL CO-EVOLUTION: THE CASE OF AUTOMOTIVE & ICT SECTORS

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.