Közgazdász Fórum
Forum on Economics and Business
26(150), 24–36.

2023/2

Features of technology development in the industrial transformation

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Based on research on the evolution of technologies, it is apparent that technology development is more and more diversified as well as much more dynamic than ever before. The relevance of the topic is given by the rapid development of technology and the uncertainty of its effects. The current paper builds on earlier research and conclusions made in relation to technology forecasting. Along with processing literature sources and drawing conclusions, the authors examine the development of technology forecasting methods in line with technological developments. Beside analysing the development-related features of technologies in the emerging industries, the paper evaluates the trends of the related scientific research. The authors attempt to find correlations among technology trends, methodology trends and the related scientific research. As a result of the analysis presented in this paper, key technology areas and related methodological consequences can be identified in the emerging industries.

Keywords: technology development, technology forecasting, emerging industries, technology transition, technology transformation.

JEL code: O32.

Introduction

The current times bring changes in many areas of life. Newer technologies pose challenges both for the industry and for researchers. The changes are often derived from megatrends or disruptors which are pinpointed by the research. Typically, megatrends are longer-term changes, while disruptors are quicker changes with a high impact. Megatrends and disruptions are usually challenging for actors because they need to change their usual processes, business models and methods. This is a challenge for many organisations, especially with short deadlines and cost-effectiveness, which is, however, necessary for long-term competitiveness.

On the one hand, this paper analyses the development-related features of technologies in the emerging industries. On the other hand, it evaluates the trends of the related scientific research from time horizon and methodology perspectives. The authors attempt to find correlations among technology trends, methodology

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trends and the related scientific research. As a result of the analysis presented in this paper, key technology areas and related key methodological consequences can be identified in the emerging industries.

Literature review and theoretical framework

Organisations with greater flexibility and adaptability to changing circumstances are better able to deal with these megatrends and disruptions (de Waal–Goedegebuure 2017). One of the contradictions of this assumption, however, is that all this is true for short-term challenges and situations that require agile action when an organisation can adapt quickly to emerging problems and opportunities. However, this adaptability is not necessarily suitable for dealing with changes that occur only gradually and over a longer period of time like megatrends (Cozzolino et al. 2017). According to the majority of researchers, megatrends are more significant in volume, they are long lasting and have profound effects, usually with a trend-like impact (Mittelstaedt et al. 2014).

Naisbitt was one of the first researchers in the literature to use the term megatrend. He defined this as a socio-economic or structural process that develops slowly but, when it occurs, it has a significant impact on many areas of life for a long time to come. Subsequent research has extended the definition to include the understanding of comprehensive social, economic, and technological changes that are slow to develop and have an impact for decades to come (Naisbitt 1982).

Of course, researchers describe megatrends differently, and one of the key differences is the time horizon. Naisbitt and Urdene (1990) point to a decade-long horizon, Utikal and Wothe (2015) refer to several decades, Galinska (2018) mentions a period of even half a century.

Some researchers (Vielmetter–Sell 2014; Groddeck–Schwarz 2013) point out that a megatrend may also result from the superimposition of smaller short-term phenomena. There is also a difference of opinion among researchers regarding the nature of the megatrend event. Some of them (Toops 2014; Hajkowicz 2015) argue that a megatrend is a relatively large phenomenon that develops slowly but ultimately leads to major changes. Others say the megatrend is not the result of a single major event, but rather a series of events. Thus, long-term trends actually result from the projections of change trajectories or the summation of interrelated trends (Rohner 2018; Malik–Janowska 2018).

In contrast to megatrends, there is far less research on disruptors. These can also be seen as factors that prevent a system from continuing to function as usual. Some people also call disruptors a “game changer” because their effects are

faster, and their outcome is usually uncertain. Compared to megatrends, which are generally global in nature, disruptors can in some cases be industry dependent. This includes the kind of change in which a new product (as a "disruptive innovation") significantly transforms a particular market in a given industry (O'Reilly–Binns 2019).

Based on the provided description, megatrends are slow-evolving, long-lasting socio-economic shifts with widespread impacts, while disruptors are rapid, immediate changes that can lead to uncertain outcomes and may be industry-specific. Organisations need agility to respond to both, but this adaptability is more crucial for handling short-term disruptions than long-term megatrends. Linthorst and de Waal (2020) point out not only prominent megatrends but also some context-specific features and identifiable features of megatrends and disruptors:

- Geographical aspect,
- Industry specificity,
- Multidisciplinarity,
- Impact on organisations.

This paper approaches changes from the perspective of technology. The authors follow the definition of Pataki (2014. 17) as "the technology is a system of expertise and tools that enables one to meet the required needs." Following this definition, three aspects can be used to outline the interpretation of a technology. Technologies can be divided into two groups based on their professional content, namely product technology and process/manufacturing technology (Steele 1989). In connection to the essence of a product (physical product or service), technologies can be grouped as core technologies, complementary technologies, peripheral technology (Trott 1998). In terms of market competitiveness, technologies can be divided into base technologies, key technologies, and pacing technology (Little 1998).

New technologies have a certain connection to the market or society needs and potential. This relationship can act as a "pull" from the user side, so some demand emerges in the market that requires some technological innovation. On the other hand, from the science side, new technology development directions are emerging and act as a "push", thus generating new market demands. As technological change usually involves a great deal of uncertainty, the field of technology forecasting is given a prominent role. It allows for the continuous recognition of how a particular technology will affect certain areas in the future. As technologies play a major role in planning the growth of business, industry, government, and society, their shrinking life cycle makes their forecasting even more necessary in every planning process.

Methodology

Based on the discussion above, technological change was defined in the frame of megatrends versus disruptors. As it can be seen, technology-level changes are mainly interpreted on the disruptor level having been in relation to certain long-term megatrends.

The purpose of this paper is to show technology development-related features from three aspects:

- Trends of the related scientific research;
- Development of technology forecasting methods;
- Development of technologies.

The current paper highlights selected references to demonstrate the sequence of conclusions related to industrial-focused technology developments. The sources of the results shown here are selected from highly cited papers, with many of them being review-type research papers, so as to offer state-of-the-art conclusions.

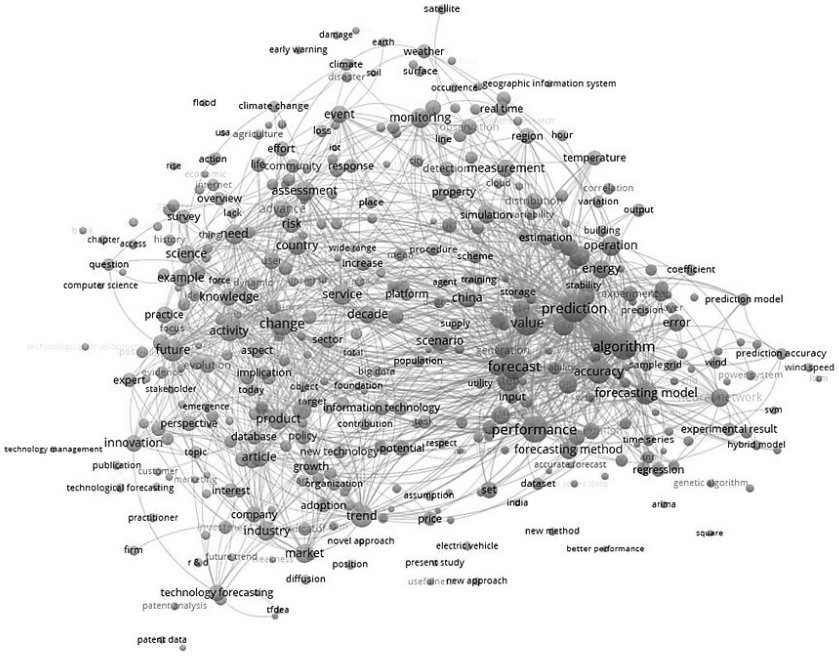

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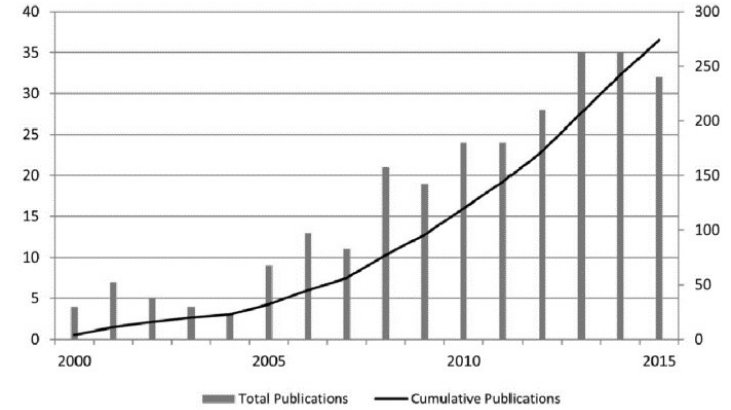
Figure 1. 'Technology forecasting' keyword search

As a general introductory overview, we reviewed around 1,000 papers between 2011 and 2021, using the VOSviewer tool. Figure 1 provides an overview of the results based on the keyword "technology forecasting". Based on the analysis shown in Figure 1, in the field of technology, research is both intensive and interrelated. The sub-clusters are close to each other and there is limited dominance of few keywords, which reflects the intensity and openness of the research field.

Results and discussion

One of the key journals in the field of technologies is *Technological Forecasting & Social Change* (see Gordon et al. 2020). Figure 2 illustrates the intensive development of technology-related research, most probably in line with the intense changes of the recent years (Bildosola et al. 2017).



Number of papers which combine bibliometrics and technology forecasting research field methods for the period 2000–2015.

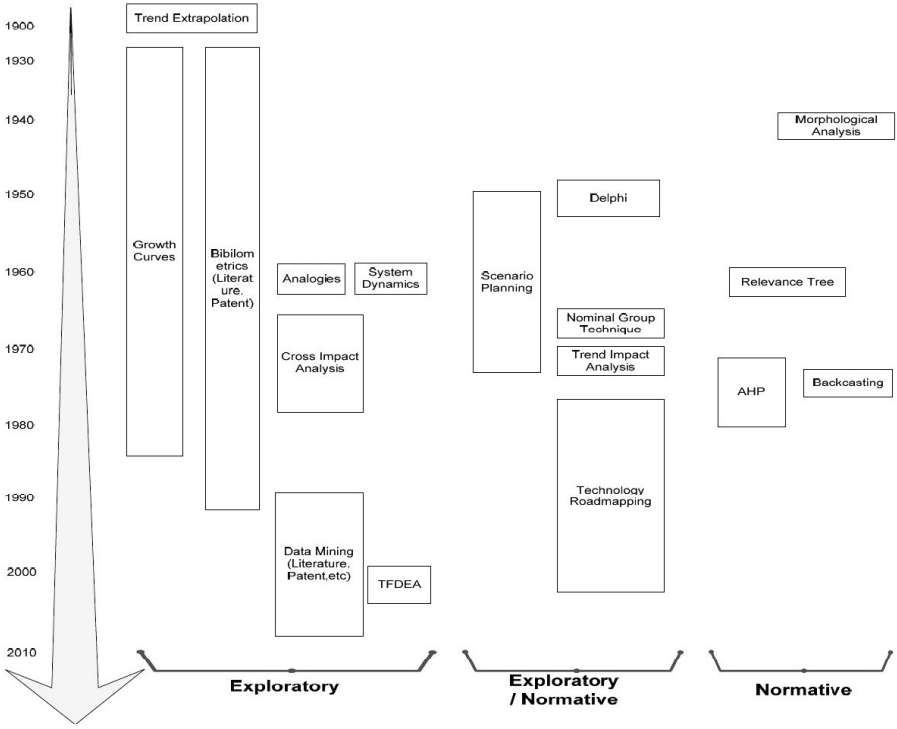
Source: Bildosola et al. (2017. 3)

Figure 2. Trend of papers which combine bibliometrics and technology forecasting research

Singh et al. (2020) shows the evolution of the technological field over time. The study analysed the development of the *Technological Forecasting and Social Change* (TF&SC) journal from 1970 to 2018 and highlights 'technology' as the predominant theme of the journal, comprising 19.7% of all articles, followed by 'innovation' at 12.5%. The themes 'energy,' 'resources,' and 'climate' contribute less, making up 4.4%, 2.1%, and 1.1% of publications, respectively. Also, between

1970 and 2009, 'technology forecasting' dominated the field, but from 2010 to 2018, the focus shifted to 'innovation', with a growing interest in 'technological development'. The recent era has seen emerging trends like 'big data', 'smart cities', and new methodological approaches. In conclusion, since 2006, there has been an increase in the number of articles related to technological fields like innovation and resources, as well as those addressing complex technological challenges.

Saritas and Burmaoglu (2015) conducted a scientometric analysis of 2,659 publications related to foresight, resulting in the identification of 4,424 keywords. The study revealed a substantial increase and diversification in foresight methods from 1991 to present, identifying 68 key foresight methods. This not only reflects the expansion of the technology foresight methodology toolbox but also, quite likely, the improved alignment of this toolbox with real-world technologies. In other words, acknowledging that new technologies are the primary drivers



Source: Cho (2013. 2089)

Figure 3. Changes in the nature of technology forecasting methods over the years

of research and that they influence research topics, this trend demonstrates the increasing complexity of technologies. This aligns clearly with the greater emergence of disruptive technologies related to the megatrends introduced at the beginning of this paper.

It is also apparent that the features of technology forecasting methods are also changing. While the classic quantitative-type methods were available as early as the beginning of the last century, nowadays the softer and more comprehensive tools and methods are arising. Cho (2013) categorised technology forecasting methods into exploratory, exploratory/normative, and normative groups (see Figure 3), emphasising that no single method is dominant and that hybrid approaches are often more effective. Also, Cho (2013) suggests that the selection of technology forecasting techniques must be informed by the nature of the technology and expertise in various forecasting models.

There is also research available on linking the relevant technology forecasting methods and the potential industries. According to Kang et al. (2013), in the realms of information technology and materials, trends and descriptive methods dominate, while monitoring is prevalent in telecommunications. Other industries generally favour a mix of monitoring, trends, and descriptive techniques, with the financial sector not applying any standard forecasting methods (Kang et al. 2013). This perspective indicates that researchers of disruptive technologies tend to concentrate their efforts on specific fields rather than addressing these technologies in a broader context. Even though disruptive technologies might be independent from industries, it is highly recommended to direct research methodologies toward defined sectors when delving into specific technology features. This sector-specific approach helps navigate the challenges presented by the growing complexity of technologies and their interconnectedness with overarching trends. Thus, tailoring research to particular industry sectors is crucial for gaining an in-depth understanding of technology-related characteristics in diverse studies.

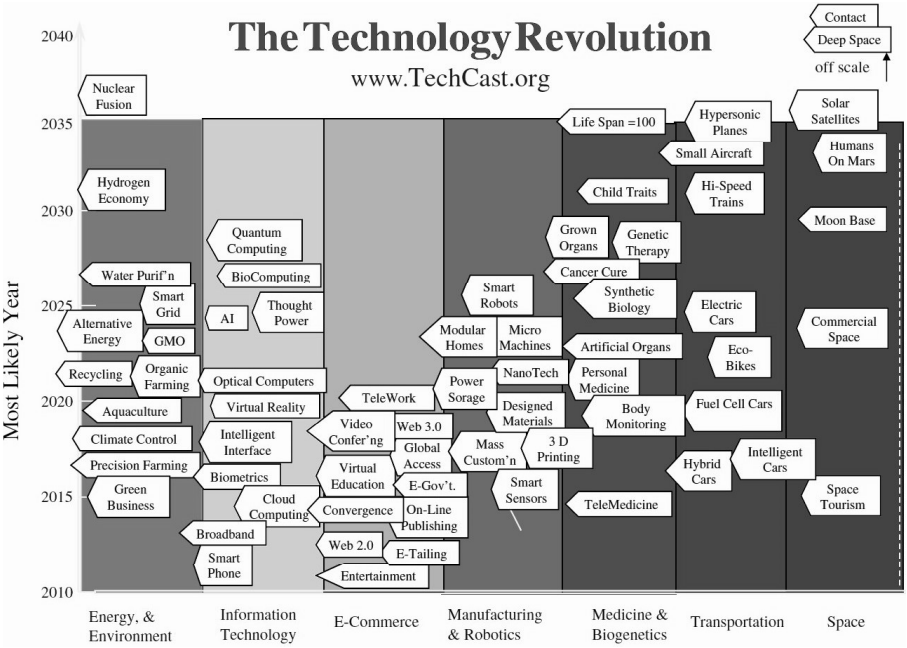
Table 1, which is based on the research conducted by Bildosola et al. (2020), gives an overview of disruptive technologies in emerging industries. It also illustrates the evolution of technology research from broad to specific focus, with ‘security’ consistently at the forefront. Initial broad terms like ‘distributed computing’ gradually gave way to specific ones like ‘fine-grained access control’, reflecting the field’s thematic specialisation and maturity (Bildosola et al. 2020).

Table 1. Most frequent keywords in the emerging industries

2008	2009	2010	2011
Distributed computing (5.6)	Grid computing (2.8)	CC security (2.4)	CC security (2.9)
Virtual computing (5.6)	Service-oriented architecture (2.8)	Virtualisation 2.4	Virtualisation (1.9)
CC security (5.6)	Virtualisation (2.6)	Privacy (1.9)	Software as a service (1.5)
	Software as a service (2.3)	Distributed computing (1.8)	Infrastructure as a service (1)
	Distributed computing (2.3)	Software as a service (1.5)	Service level agreement (1)
	CC security (1.8)	Service-oriented architecture (1.3)	Privacy (1)
	Data centre (1.5)	Infrastructure as a service (1.2)	Distributed computing (0.9)
	Web services management (1.5)	Platform as a service (1)	Platform as a service (0.9)
	Privacy (1.3)	Data centre (1)	Mobile CC (0.8)
	Utility computing (1.3)	Grid computing (1)	Access control (0.7)
2012	**2013**	**2014**	**2015**
CC security (2.6)	CC security (8.8)	Mobile CC (2.3)	Big Data (0.9)
Virtualisation (1.7)	Virtual machine (4.9)	CC security (1.2)	Mobile CC (0.7)
Virtual machine (1.3)	Mobile CC (4.7)	Virtualisation (1)	Digital storage (0.7)
Privacy (1.3)	Privacy (4.5)	Load balancing (1)	Quality of service (0.5)
Service level agreement (1.2)	Distributed computing (4.3)	Quality of service (0.8)	Virtual machine (0.5)
Infrastructure as a service (1.1)	Virtualisation (4.2)	Resource allocation (0.8)	Web services (0.5)
Software as a service (1)	Quality of service (3.3)	Access control (0.7)	Energy efficient (0.5)
Energy saving (0.9)	Energy saving (3.3)	Software as a service (0.7)	Task scheduling 0.5
Distributed computing (0.9)	Software as a service (3.2)	Task scheduling (0.7)	Cryptography (0.4)
Quality of service (0.9)	Infrastructure as a service (2.9)	Fine-grained access control (0.6)	Customer relationship manager (0.4)

Source: Bildosola et.al. (2017. 11)

At this point of the discussion, the dilemma of the sectoral focus and the specific technology development trends need to be interpreted. Halal (2013) presents a thorough overview of developing technologies in a chronological way, with a classification into the related sectors (see Figure 4). It highlights the anticipated milestones for 70 emerging technologies across seven sectors, detailing their journey to reaching a 30% adoption rate, which is indicative of mainstream usage. This method ('TechCast') contrasts with traditional forecasting by incorporating empirical data to inform expert judgment, thus striving for scientific rigor and reducing forecasting uncertainty significantly. From the aforementioned details, it becomes evident that analysing and understanding the interrelationships among technologies is essential. Considering the definitions of megatrends and the nature of disruptive behaviours, especially in the context of today's significant changes, it is clear that the complexity of technological shifts necessitates research approaches that address technologies both individually and as a whole.



Source: Halal (2013. 1637)

Figure 4. The technology revolution and the affected industries

Both the trends of technology-related research explained above and the definition of megatrends clearly emphasise the importance of increasing the diversity and complexity of the technological field. Therefore, as a conclusive direction, it can be pointed out that the one-to-one linkage of the specific technologies is most probably a less appropriate way to approach the research. Consequently, the authors propose to focus on the interrelations of the various disruptive technologies. Figure 5 illustrates this concept, which includes technology-to-technology linear relations and the content-wise relation. The latter one is probably more challenging, as it shows the need to understand the sub-levels of various technologies from a competence, discipline point of view.

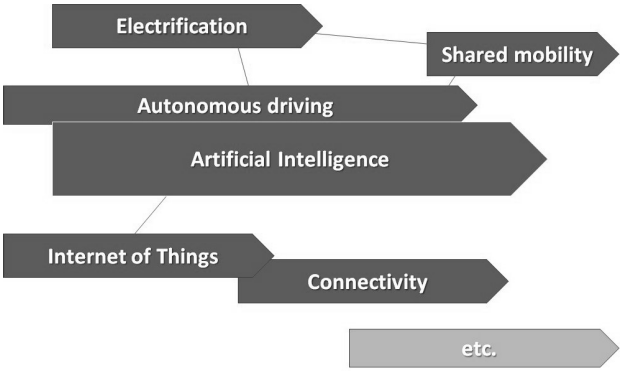


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Figure 5. Relations of various technologies to be researched (example)

A single technological trajectory often necessitates the convergence of multiple technologies. Furthermore, their interplay may give rise to novel technological innovations. In light of this, a fresh interpretative approach is warranted. Currently, there is no definitive method for predicting the outcomes of technological convergences and their cumulative impacts.

This approach can be built on a disciplinary-based analysis, surveying the multidisciplinarity of the new technologies (see Figure 6). When multiple technological sectors intersect and merge, they often give birth to new and defining technologies that can radically transform the industry landscape. For instance, we can observe this phenomenon in the field of autonomous mobility. In the development of autonomous vehicles, four technological pillars stand out

for illustration: 5G, HD maps, V2X communication, and Artificial Intelligence (AI). These foundational technologies are revolutionary in their own right, but when intertwined, they open up new possibilities. The diagram illustrates the new technologies emerging from the intersection of various technologies. In this case, by combining different technologies, we can achieve a new level of autonomous mobility, where vehicles rely not only on their own sensors but on all available data sources, ensuring maximum safety and efficiency. Drawing on the analogy of studying various disciplines, we can interpret aspects related not only to multidisciplinarity but also to interdisciplinarity and transdisciplinarity when examining the relationships of disruptive technologies. This subject is an active research area for the authors and warrants further investigation. Traditional forecasting methods often overlook the evolution of technological relationships and their combined potential impact. Moreover, these methods struggle to track the diffusion of technologies. Current forecasting methods often overlook the evolution of technological relationships and their cumulative potential impact. Moreover, these methods struggle to accurately track the diffusion of technologies.

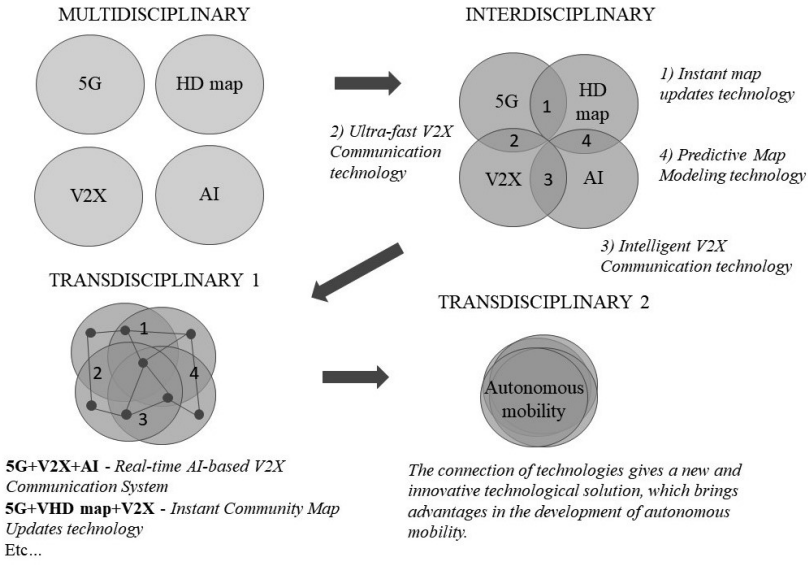

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Figure 6. An analogue conceptual approach proposed for researching the interrelations of new technologies

Conclusions

The paper introduces the concept of megatrends and, in relation to this, it explores the nature of disruptors. Further interpretations derived the technology changes into the context of disruptors, emphasising the importance of understanding the intricate interconnections of technological changes. Based on the research of relevant literature review results, the authors illustrate the deployment of disruptor logic to specific technology level view, according to referenced trends. The growing complexity of related research and technology forecasting methods reflect the correspondence with the changing nature of technology systems or industries instead of focusing on single technologies. In conclusion, the research underscores the necessity for more in-depth studies to grasp the interplay of specific technologies within a sector. Additionally, there is a pressing need to devise a method for assessing these effects.

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