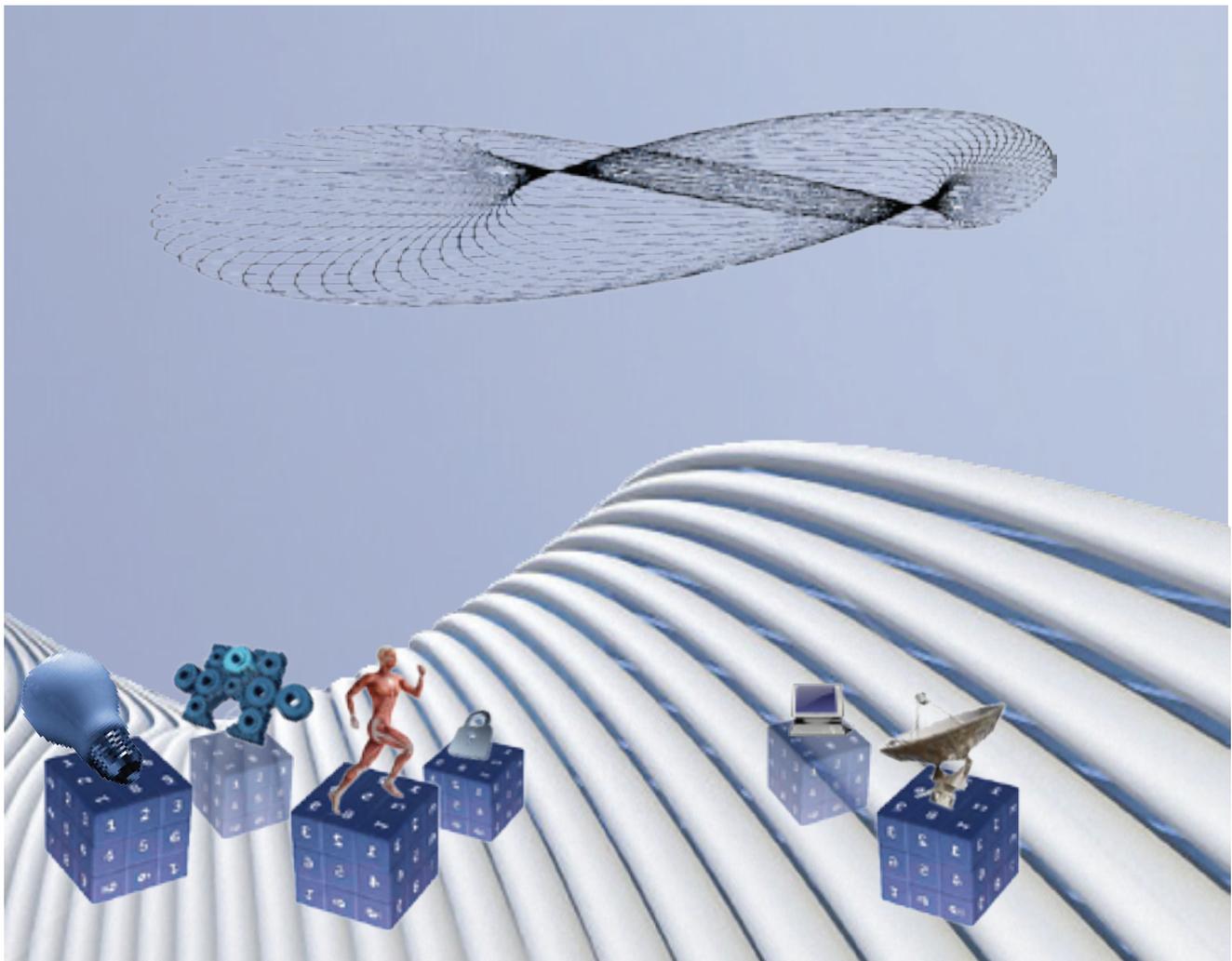


International Foresight of the 2000s: Comparative Analysis *

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The article summarizes the experience of technology Foresight studies carried out since 2004 in China, Japan, France, UK, USA and the EU. Despite the many differences observed between the studies, we note some significant common issues.

All the foresight studies we analysed give priority to energy; health, medicine, nutrition; biotechnology / life sciences; nano- and microsystems technology; and also to ICT, electronics, manufacturing, process and material technology, environment, defence and space technologies.

Herewith, all the technology forecasts we compared assumed that progression in sustainability/environment and ICT was a prerequisite for progress in other areas.

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Technology Foresights

Since the early 1990s, technology foresights have played an increasingly important role in the innovation and technology policy of various actors. A content analysis of technology foresights may help gain information on basic technology trends. International comparisons are a particularly efficient means to identify overall trends.

Despite the existing diversity of actors, backgrounds, and goals of such a project and despite the unavoidable associated methodological difficulties of a comparison, the meta-analysis of technology foresights carried out by the VDI Technology Centre [Braun *et al.*, 2013] contributes to an overall picture regarding the concept of future technological developments.

Methodology

Methodologically, the study is based on three studies also carried out by the VDI Technology Centre, which elaborated on the commonalities and differences of selected European, American, and Asian studies:

1. An overview study ‘Internationale Technologieprognosen im Vergleich’ [International Technology Foresights in Comparison] from 2004 [Seiler *et al.*, 2004];
2. An update on the above publication ‘Aktuelle Technologieprognosen im internationalen Vergleich’ [Current Technology Foresights in International Comparison] from 2006 [Holtmannspötter *et al.*, 2006];
3. The study ‘Technologieprognosen — Internationaler Vergleich 2010’ [Technology Foresights — International Comparison 2010] [Holtmannspötter *et al.*, 2010].

The goal of the comparative study presented here is to provide an overview of the essential content and foci of major technology forecasts from abroad. In this way, Germany’s Federal Ministry for Education and Research (BMBF) and decision makers elsewhere will get additional information in a concise and clear form to shape research policy and strategy development. In the present study, research for suitable technology forecasts was, on the one hand, focused on Germany’s direct competitors from North America and Europe, and, on the other hand, on emerging countries and future economic powers, mainly from Asia but also from other regions of the world. Moreover, in comparison with previous studies, research was expanded through supranational activities within the context of the ‘European Forward Looking Activities’ of the European Commission and the European Technology Platforms. Based on predefined selection criteria,¹ we selected national technology foresights from five countries (China, France, Japan, USA and UK) as well as studies on Key Enabling Technologies (KETs) by the European Commission for the current comparative study. The studies examined differ with regard to goals, levels of detail, fields of technology, socio-economic data included, as well their time horizon. To achieve a clearly structured comparison of the technological forward-looking information, despite such differences, the studies had to be subjected to a common analysis matrix which illustrates commonalities and conspicuous deviations. Therefore, the essential information and forecasts of the respective technology studies were elaborated with regard to the following 16 topical fields:²

- Transport and Traffic, Logistics
- Aerospace Engineering
- Construction and Housing

¹ Inter alia, country groups, contracting parties; geographical scope and time-based delimitation; socio-economic topics, language, cf. [Braun *et al.*, 2013].

² Here, it must be pointed out that the validity of these information and forecasts was not evaluated within the context of the meta-analysis: only the most important forecasts were filtered out, regardless of whether the authors of this article considered them to be realistic, probable, improbable, unrealistic or probably even absurd.

Table 1. **Characteristics of selected technology foresights**

Country	Study	Contracting Party	Executive Institution(s)	Published in	Time Horizon	Sources
China	Science & Technology in China: Roadmap for 2050	Chinese Academy of Sciences	Various	2010-2012	2050	[CAS, 2010]
France	Technologies Clés 2015	Ministry for the Revival of Production – Directorate General for Competition, Industry and Services (DGCIS)	Institutions	2011	2015–2020	[DGCIS, 2011]
Japan	9 Japanese science and Technology forecast	Ministry of Education, Culture, Sports, Science and Technology (MEXT)	Expert Panel	2010	2039	[NISTEP, 2010a; NISTEP, 2010b; NISTEP, 2010c; NISTEP, 2010d]
UK	Technology and Innovation Futures	Government Office for Science – Department for Business, Innovation and Skills	Foresight Horizon Scanning Centre	2012	2020	[BIS, 2010; BIS, 2012]
USA	Reports of President's Council of Advisors on Science and Technology	President of the United States of America	President's Council of Advisors on Science and Technology (PCAST)	2010-2012	2015+	[PCAST, 2010a; PCAST, 2010b; PCAST, 2010c; PCAST, 2012a; PCAST, 2012b; PCAST, 2012c]
EU	Key Enabling Technologies, KET	European Commission	High Level Expert Group (HLEG)	2011	2020+	[European Commission, 2011; European Commission, 2012]

Source: VDI Technologiezentrum.

- Marine Technology and Shipping
- Energy
- Nano- and Microsystem Technology
- Material Science (sometimes referred to as Material Engineering)
- Production and Process Engineering
- Optical Technologies
- Information and Communication Technologies
- Electronics
- Biotechnologies and Life Sciences
- Health (including Medical Engineering) and Nutrition
- Sustainability and Environment
- Defence and Security
- Services

With this, the study provides a qualitative classification of the 16 topical fields in question — always in relation to the respective study of the individual country at the time of its development or publication. We did not carry out a quantitative assessment of the relevance of technological topics or of a state's priorities in terms of research policy. Nor was it possible to compare the political or strategic effects of technology foresights based on the results of these studies.

Characteristics of selected technology foresights

Within the context of the current meta-analysis, it can be stated that there are significant differences between the technology studies examined with regard to the range of topics and their depth. On the one hand, very broad-based studies exist which deal with the respective technologies only in bul-

let-point style (e.g. from Japan); on the other hand, there are studies that discuss particular fields of technology in great detail (e.g. from China). The studies from the USA are an example of a very detailed approach to specific fields of technology, which due to their large number also cover a wide range of topics.

Content Priorities

Despite the differences between the technology studies examined, we noticed similarities in priority settings: all the studies deal exclusively with the topics of Energy, Health/Medical Engineering/Nutrition, Biotechnology/Life Sciences and Nano-/Microsystem Technology. Comparing the results of the 2013 comparative study to those of the previous studies, we observe that the discussion about the topical fields of Energy, Health, Nano-, Bio-, Optical Technologies, Environment and Aerospace Engineering gathered significant momentum over almost a decade. In contrast, topics such as ICT, Material Engineering, Electronics and Transport showed a loss of interest in comparison to previous decades. While the arising discussion about the convergence of technological fields (Biotechnology, Nanotechnology, Materials, and ICT) was the result of the analysis in the 2004 comparative study, the topic of Sustainability/Environment emerged as a demand-oriented key issue in the 2006 comparative study. In the analysis of 2010, Energy was the key issue of the technology foresight studies examined.

The specific feature of the latest comparative study (2013) is the awareness that with the *visible* key issues of Energy & Health, on the one hand, and Bio- & Nanotechnologies on the other hand, two demand areas and two technology areas were regarded as the ‘big’ issues. Moreover, it can be observed that the topics of Sustainability and Environment as well as ICT are *invisible* key issues of the current comparative study. Unlike in previous national technology foresight studies, in the latest technology forecasts these two topics are, in most cases, not regarded as independent areas; rather, their application is cross-cutting to other areas.

Key Messages of the Technology Foresights for the Individual Topical Fields

Below, the key messages of the technology foresight studies for the individual topical fields are summarized with regard to their content. In all the technology foresight studies considered here, great attention is paid to the topic of **Energy**, attaching as much importance to coal technologies as to renewable energy sources (solar, wind, water, biomass, and geothermal), nuclear energy, and nuclear waste treatment technologies. However, even new or alternative technologies such as the non-conventional recovery of oil and gas resources as well as technologies for energy storage and saving (smart grids) and the efficient conversion/use of energy, are of special relevance. These technologies, which belong to the topic area of **Biotechnology and Life Sciences**, are highlighted as Key Enabling Technologies — they have important applications in the field of Health and Nutrition in particular, and also in Production, for example for the development of clean and sustainable process alternatives in industry and agriculture. The fields identified as forward-looking include, among others, Lab-on-a-Chip methods, further research into ‘omics’ technologies,³ stem cell research and ‘tissue engineering’, synthetic biology and the application of white biotechnology in new areas (e.g. textile, paper or perfume industries). Great importance is also attached to further developments of biotechnological processes for agriculture (e.g. biological fertilizers, molecular biological plant breeding), for modern animal breeding and for resource conservation. Progress in the development of new techniques for rapid diagnosis is expected as a result of the further development of membrane techniques in microfluidics and molecular biology.

In the field of **Health, Medical Engineering and Nutrition**, statements are made on reproductive medicine, on the prevention and healing of severe chronic dis-

³ As a suffix, ‘omics’ characterizes the aspects of modern biology that deal with the analysis of the entirety of similar individual elements e.g. genomics, metabolomics, proteomics, etc.

eases and infectious diseases as well as on biosafety, nutrition, and food safety. Continuing penetration of the health sector by Biotechnologies, ICTs, Nanotechnology, Microsystem and Material Engineering is forecasted. In the field of Medical Engineering, functional imaging techniques, telemedicine, personalized medicine, lab-on-chip systems, regenerative medicine, advanced instrument technology, nano-biomedical technologies as well as minimally invasive methods are said to have great potential in the future.

Much attention is also paid to the topic of **Nano- and Microsystems Technology**, in particular as a cross-cutting technology and 'Enabling Technology.' Its convergence with numerous other disciplines such as Material Engineering, Biotechnologies, and ICTs raises expectations for important technological breakthroughs. Nanomaterials, micro-apparatus and reactors, sensors and sensor networks as well as thin-film techniques are considered to have great potential. Increased use of nanotechnologies and materials in everyday applications for health, environment and energy is expected.

Important aspects, or rather forecasted developments, in the field of ICT comprise the development of a service industry for data and knowledge, the convergence between ICT and other disciplines, access to information, data, applications and services — anytime and anywhere, grid and cloud computing, the *internet of things*, next-generation networks, issues concerning data and communication security, as well as man-machine interactions.

In the field of **Production and Process Engineering**, increasing importance is attached to the use of new resources and energy sources, to technologies that increase efficiency or to reduce resource consumption, to system integration, to the development of green products in the processing industry as well as to recycling.

In the field of **Material Science**, increased importance (and progress) is expected in terms of functional, smart, and recycling-oriented, bio-inspired materials and for the issue of recycling and the reuse of materials. Moreover, progress concerning methods for non-destructive materials testing is anticipated.

In the field of **Sustainability, Environment and Resource Scarcity**, global climate change, river and environmental quality (the biological-geochemical connection between land, river, coast), urbanization, environmental quality (control and removal of environmental pollution) and biodiversity, as well as the restoration of damaged ecosystems are paramount. Discussions are also happening now about technological applications for the water environment/water ecology, air treatment, for the improvement of photocatalytic processes, the remediation of soil, waste disposal and treatment as well as for the creation of a sustainable society. Moreover, as far as resource scarcity is concerned, the field of sustainability and environment is dealt with across all other technological fields.

In the field of **Electronics**, reference is made to its convergence with other technological fields, such as micro- and nanotechnologies (increasing miniaturization, semi-conductors) and biotechnology (DNA computing). The increasing importance of power electronics and the use of electronics in communication as well as in the field of energy (solar cells, smart grid technologies, battery technology) is forecasted.

In **Defence and Security**, the focus is often on the security of ICT systems and applications, crisis management and disaster control, general civil security, prevention of crime, and also on the security of raw materials.

With regard to the topical field of **Aerospace Engineering**, innovation impetuses concerning the expansion of the human scope of action are expected from micro- and nanoelectronics, drive technologies, and other fields. In Aerospace Engineering, progress is forecasted for lightweight and

miniature spacecraft and loading capacities, as well as advancement towards the permanent stay of humans in outer space.

In **Transport and Traffic, and Logistics**, it is the development of low-emission vehicles, increasing penetration in the transport and logistics sector of ICTs (driver assistance systems), the trend towards smart transport networks and the support of resource-saving driving behaviour (e.g. car sharing) that is at the forefront of progress. The increasing importance of system engineering and complex modelling and simulation methods in the transport sector are also being discussed. According to the technology foresight studies we have examined, there is particular potential for the further use of ICTs as well as for photonics and micro- and nanoelectronics in transport, traffic and logistics.

Special market potential is seen in **Optical Technologies**, in particular in the application of photonics for imaging techniques in medicine, in photovoltaic applications and smart lighting systems as well as in 'green photonics.' Here, an increasing convergence with electronics is assumed.

Regarding the topical field of **Marine Technology and Shipping** it is expected that the industrial exploitation of seabed resources as well as the generation of wave, tidal and flow energy will be possible in future. The further ecological development of marine bioindustry and the fixation of carbon dioxide under the seabed are thought to have great potential. The same applies to the field of **Construction and Housing**, in particular in technologies for the optimization of energy efficiency and for the careful use of resources.

In the field of **Services**, new service concepts are forecasted due to the increasing hybridization of production.

Changes in the topical fields over time

The following figures show how topical priorities have shifted over time⁴ and which of the 16 fields of technology are highlighted, and how these fields are discussed in the studies. Thus, this comparison provides a qualitative categorization of the 16 topical fields under consideration — always in reference to a particular country at a certain point in time. However, it does not provide a quantitative assessment of the relevance of technological topics or the priorities of a country in terms of research policies. Neither is it possible, based on the results of these studies, to compare the political and strategic effect of technology foresight studies. The fields of technology which were discussed most in both the 2004 comparative study (Fig. 1) and in the current (2013) comparative study (Fig. 2) are marked in colour. In 2004, these were ICT, Electronics, and Material Sciences. Over time, a reduced analytical intensity, with a particular downward trend for ICT, could be observed in these three technological fields.

The four major topics of the 2013 comparative study — Energy, Biotechnology / Life Sciences, Health, Medical Engineering, Nutrition, and Nano- and Microsystem Technologies — have shown a clear upward trend throughout all the studies over time. The topics of Biotechnology / Life Sciences and Nano- and Microsystem Technology could even compensate a temporary downward trend (2004-2010).

At this point, the convergence between ICT and other disciplines should again be noted: many other fields of technology consider ICT as an 'Enabling Technology.' In other words, progress in ICT is often the prerequisite for further developments in other fields. Thus in later technology foresight studies, ICT is not regarded as an independent field, but its application/input is considered cross-cutting to other sectors such as Transport and Traffic, and Logistics.

⁴ The more often a topic was dealt with, the higher it is ranked in the topic column. The pillars reflect the respective ranking of the technology fields in the comparative studies of 2004, 2006, 2010 and of the present study 2013.

Figure 1. **Historical development of topical fields which were most discussed in the comparative study of 2004**

2004	2006	2010	2013
ICT	Sustainability and Environment	Energy	Energy
Electronics	ICT	Sustainability and Environment	Biotechnology / Life Sciences
Material Science	Biotechnology / Life Sciences	Health, Medical Engineering, Nutrition	Health, Medical Engineering, Nutrition
Biotechnology / Life Sciences	Health, Medical Engineering, Nutrition	ICT	Nano- and Microsystem
Health, Medical Engineering, Nutrition	Energy	Transport and Traffic, Logistics	ICT
Production and Process Engineering	Production and Process Engineering	Biotechnology / Life Sciences	Production and Process Engineering
Energy	Material Science	Defence and Security	Sustainability and Environment
Nano- and Microsystem	Nano- and Microsystem	Construction and Housing	Material Science
Transport and Traffic, Logistics	Transport and Traffic, Logistics	Production and Process Engineering	Electronics
Defence and Security	Aerospace Engineering	Material Science	Defence and Security
Sustainability and Environment	Construction and Housing	Nano- and Microsystem	Aerospace Engineering
Aerospace Engineering	Defence and Security	Aerospace Engineering	Transport and Traffic, Logistics
Marine Technology and Shipping	Electronics	Marine Technology and Shipping	Optical Technologies
Services	Optical Technologies	Optical Technologies	Marine Technology and Shipping
Optical Technologies	Services	Services	Services
Construction and Housing	Marine Technology and Shipping	Electronics	Construction and Housing

Source: VDI Technologiezentrum.

Finally, although the topics of Electronics and Material Engineering experienced a significant decline until 2010, the current comparison shows that both fields have again risen higher on the research agenda.

Comparison of Decades

Table 2 below illustrates the change of topics over time in technology foresight studies throughout almost a decade (2004–2013). The relative change in the relevance of topics in the technology foresight studies analysed in 2013 compared to their relevance in the comparative study of 2004 is shown as an upward, downward or constant arrow.

Table 2 demonstrates that the topics of Energy, Biotechnologies / Life Sciences, Health, Medical Engineering, Nutrition, Nano- and Microsystem Technology, Sustainability and Environment, Optical Technologies as well as Aerospace Engineering are more frequently discussed compared to in the comparative study of 2004 (although in part, interim declines could be observed).

On the other hand, the discussion about the topical fields of Material Science, Electronics, Transport, Traffic, and Logistics, Marine Technology and Shipping, Services, and Information and Communication Technologies lost their intensity within almost a decade. However, the relative frequency of analysis of Production and Process Engineering, Construction and Housing, and Defence and Security remained constant.

Conclusion

As noted above, for the last two decades technology foresight studies gained an increasingly important role in the innovation and technology policy of many different actors. The enormous increase in technological knowhow, the growing complexity of technologies and the necessity to efficiently utilize scarce resources to boost innovation are only a few of

Figure 2. **Historical development of the topical fields most intensely discussed in the comparative study of 2013**

2004	2006	2010	2013
ICT	Sustainability and Environment	Energy	Energy
Electronics	ICT	Sustainability and Environment	Biotechnology / Life Sciences
Material Engineering	Biotechnology / Life Sciences	Health, Medical Engineering, Nutrition	Health, Medical Engineering, Nutrition
Biotechnology / Life Sciences	Health, Medical Engineering, Nutrition	ICT	Nano- and Microsystem
Health, Medical Engineering, Nutrition	Energy	Transport and Traffic, Logistics	ICT
Production and Process Engineering	Production and Process Engineering	Biotechnology / Life Sciences	Production and Process Engineering
Energy	Material Engineering	Defence and Security	Sustainability and Environment
Nano- and Microsystem	Nano- and Microsystem	Construction and Housing	Material Engineering
Transport and Traffic, Logistics	Transport and Traffic, Logistics	Production and Process Engineering	Electronics
Defence and Security	Aerospace Engineering	Material Engineering	Defence and Security
Sustainability and Environment	Construction and Housing	Nano- and Microsystem	Aerospace Engineering
Aerospace Engineering	Defence and Security	Aerospace Engineering	Transport and Traffic, Logistics
Marine Technology and Shipping	Electronics	Marine Technology and Shipping	Optical Technologies
Services	Optical Technologies	Optical Technologies	Marine Technology and Shipping
Optical Technologies	Services	Services	Services
Construction and Housing	Marine Technology and Shipping	Electronics	Construction and Housing

Source: VDI Technologiezentrum.

Table 2. **Change in topical relevance in technology foresight studies**

Topic	2004–2013
Energy	↗
Biotechnologies and Life Sciences	↗
Health (including Medical Engineering) and Nutrition	↗
Nano- and Microsystem Technology	↗
Sustainability and Environment	↗
Optical Technologies	↗
Aerospace Engineering	↗
Production and Process Engineering	→
Construction and Housing	→
Defence and Security	→
Material Science	↘
Electronics	↘
Transport and Traffic, Logistics	↘
Marine Technology and Shipping	↘
Services	↘
Information and Communication Technology	↘

Source: VDI Technologiezentrum.

the reasons. Ever shortening innovation cycles accompanied by high competitive pressure add to the growing demand for knowledge about the future (which is required for the strategic decision making of governments, international organizations and companies).

National and interdisciplinary technology foresight studies provide an insight into the assessments and expectations of governments regarding emerging technology development and in part also into the strategic planning nationally. International organizations as contracting parties of these foresight studies complement this point of view through their globally or at least supra-region-

ally, oriented assessments. Technology studies on behalf of multinational groups contribute to an industry-specific viewpoint.

In particular, Germany as an exporting nation strongly oriented towards high-technology products is dependent on the early identification of new trends and development paths. Such a need is taken into account not only by self-generated forecasts, but also by the monitoring of internationally available studies. A meta-analysis of technology foresight studies can contribute to building up an overall picture regarding future technology development and to elucidating national strengths and characteristics by deduction. Content analysis of technological foresight studies helps to acquire immediate information on basic technology trends. International comparisons are a particularly efficient way to identify overall trends.

The fourth comparative technology study carried out by the VDI Technology Centre provides an overview of the essential content and priorities of recent and important technology forecasts from abroad. It thus offers a qualitative categorization of 16 analysed topic areas — always in reference to the respective study of a country at the point of time of its preparation or publication. Within the context of this meta-analysis, we can conclude that, in part, the individual technology studies analysed differ considerably in terms of both their range of topics and their depth. On the one hand, very broad-based studies exist which deal with the respective technologies only briefly, in bullet-point style (e.g. from Japan); on the other hand, there are studies that discuss particular fields of technology in great detail (e.g. from China). The studies from the USA are an example of a very detailed approach to specific fields of technology, which, due to their large number also cover a wide range of topics. Despite the diversity of the studies analysed and the diversity of the system of concepts, it appeared that the analysis grid used here is adequate to the subject. This means that the essential information of the studies analysed could be allocated, almost without exception,⁵ to one or two of the 16 topical fields of the analysis grid. Such a basic assessment of the appropriateness of the analysis grid has not changed over the four comparative studies conducted to date. Against this background it could be assumed that there are also only a few changes in the intensity of the overall engagement in these topical fields. At the same time, in some cases it seems that there are drastic upward and downward movements, as Table 2 illustrates. This is all the more surprising if one considers that the topic fields of the analysis grid have a high level of aggregation and technology forecasts often concern longer time horizons of 10 or more years.

In the comparative study of 2013, we saw a clear prioritization of Energy, Health, Medical Engineering, Nutrition, Biotechnologies / Life Sciences and Nano- and Micro-system Technology topics. The technology foresight studies also dealt with the topical fields of ICT, Electronics, Production and Process Engineering and Material Science, Environment, Defence, and Aerospace Engineering. The results of all the technology foresight studies analysed, in particular in the topical fields of ‘Sustainability and Environment’ as well as ‘Information and Communication Technologies’ showed that their further development is often a prerequisite for progress in other areas. 

⁵ The following topical fields of the 9th Japanese Technology Foresight Study were not classifiable: Strengthening of the management possible/required due to the scientific-technical progress; Infrastructure technologies for the support of the daily livelihood and the industrial basis; Observation, monitoring, simulation and forecast, assessment, consensus building.

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