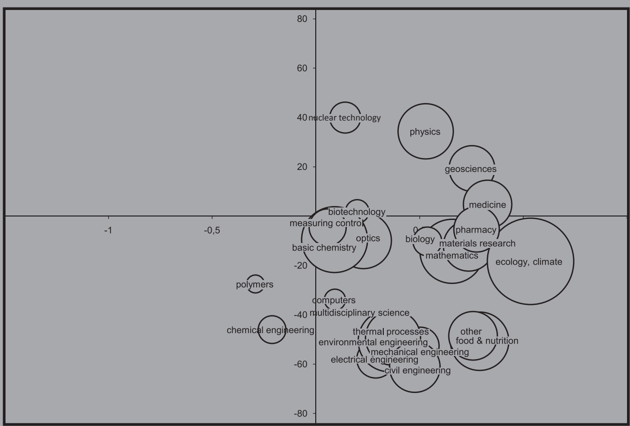
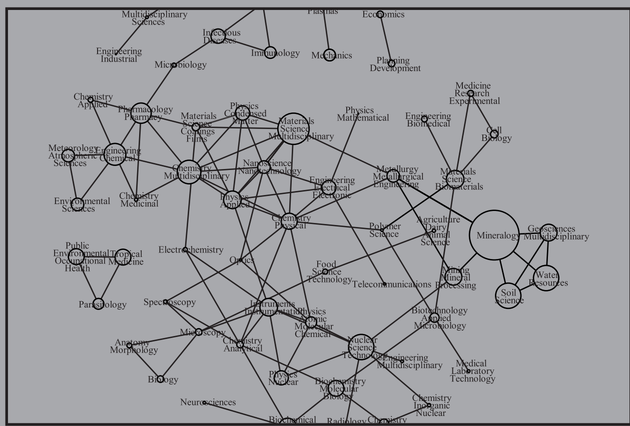
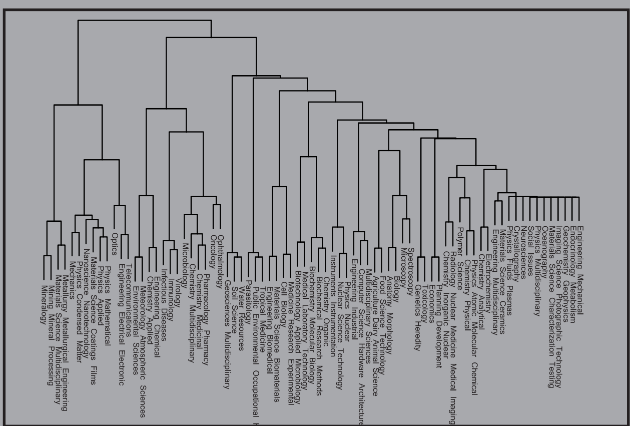
Technische Universität Berlin

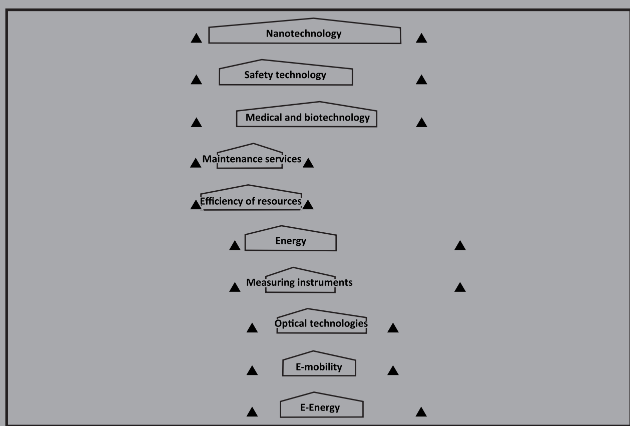
STANDARDISATION FORESIGHT –
AN INDICATOR-BASED, TEXT MINING AND DELPHI METHOD

FOUR ESSAYS









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Standardisation Foresight – An Indicator-based, Text Mining and Delphi Method

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Summary

Despite the variety of potent economic effects and impacts of standardisation on the technological development of innovations, the field of standardisation research is a fairly under-represented research area. Only the results of recent years of empirical research attracted more interest for the economic functions and the associated implications of standards as well as the impact on the actors of the national innovation system (NIS). Probably due to this circumstance, there has been no systematic foresight approach for identifying future standardisation issues and the consideration of economic and political implications of standardisation in national technology foresight programs has been neglected.

Studies of current practice show that so far members of the existing standardisation committees produced new ideas for standardisation issues sometimes supported by specific measures of national standards bodies. But especially for emerging disciplines and technology areas in which several standardisation committees must work together or if new fields have no representation in the existing committee structure, it is necessary to identify possible topics and their specific standardisation issues and, in addition, identify new stakeholders and actors for this new field, in order to develop quality output.

This dissertation deals with the question of how a foresight approach should be implemented to cover specific requirements of standardisation processes. The thesis contributes to the development of a systematic approach by identifying possible methods. Main focus is the use of method combinations and the expandability of established foresight methods such as Delphi surveys with method of S&T indicator analysis, and its extensibility with methods for bibliometric analysis, text mining and network analysis. To describe the various methods, mostly exploratory analyses are carried out, intended to give practical insights on how to conduct such analyses.

Due to the cumulative nature of this thesis, there is a possibility for overlapping sections and duplications in the text in different thematic areas. In addition, some elements of the approach were further developed and methodically completed in the course of time of this work. These duplications are mainly part of the motivation and are basis for the derivation of arguments of the individual articles; other overlaps were explicitly included at the request of the journal-reviewers of the article. This applies particularly to those parts of the motivation of standardisation foresight, the description of the economic effects of standards, and the characterisation of the chosen approach for the identification of future standardisation issues and the description of the selected indicator set. Despite these overlapping parts, however, each essay takes its own different perspective on the approach. Thus, the individual essays address for example, an assessment approach, a detailed de-

scription of the analyses and the results of the indicator approach, the used Delphi method, as well as additional methods to supplement the approach. A recurring element is the view on the nanotechnology field, which serves as a case study.

The first chapter will introduce the concept and methods of this thesis. On this, answers to the following questions are being sought: Is there a need for a systematic foresight approach to identify future issues of standardisation? What are common features of existing foresight approaches? What is a possible implementation of such an approach? What are alternative and complementary methods for the approach? And how should the results of the approach be assessed? Thus, the article addresses a detailed description of the motivation and the requirements for a standardisation foresight approach. On this, potential problems are described, which result from the current practice to identify new topics for standardisation. Through the description of similarities and differences between the chosen approach and the technology foresight approach will be further specified. Based on the motivation and requirements, possible methods, their alternatives and expansion options were considered.

The second essay, "Identifying Future Fields of Standardisation – Methodology and Empirical Experiences", forms the second chapter and addresses the underlying model of economic effects of standards and the role of different standard types in the R&D process. Mainly it provides, however, a detailed description of the results of the indicator approach and of the Delphi survey for the subject area nanotechnology. It also discusses a conducted study on the foresight practice of international standardisation organisations in more detail.

The third essay "Identification of Future Fields of Standardisation – An Exploratory Application of the Delphi Methodology" emphasises the foresight part of the approach. In addition to the considerations of the approach objectives, conditions for an "optimal" foresight approach for standardisation foresight are described. However, the essay addresses the assessment of the selected Delphi approach, specifically the extensibility of Delphi surveys using combinations of methods and describing the new application areas for the Delphi method. Furthermore, the suitability for the identifying appropriate stakeholder groups is assessed. On this, main characteristics of the different interest groups in the standardisation process and a derivation of the corresponding indicators are described. The article also specifies the modifications to the original method, which have been made to address practical implementation problems. The essay also includes a comparative analysis of the Delphi study and a theoretical foundation for S&T indicators and the Delphi method and the role of standards and their economic effects.

The fourth essay, "Supporting Successful Standardisation Processes in Complex Emerging Fields through Quantitative Analysis – The Case of Nanotechnology", concludes the development of the foresight approach with a methodical expansion of the indicator part used in essays 1 to 3. Considering some of the key challenges of successful standardisation in complex and heterogeneous emerging technologies, it presents a set of quantitative methods, which allows the identification and integration of subjects and researchers in the standardisation process in these fields of research. They offer the possibility of an exploratory structural analysis for emerging technologies. By identifying the multi-layered complex structures of scientific fields, they help to identify areas of action for standardisation. For the example of nanotechnology three possible ways with different level of detail are considered: (1) Description of a historical outline using time series, (2) cluster and network analysis of co-classifications, and (3) analysis of word frequencies and co-occurrences of key words as a method of text mining.

Chapter five concludes with a review on five years standardisation work in the field of nanotechnology. In this chapter a qualitative assessment of the standardisation foresight approach is presented. Based on data collected in 2006, the results of the foresight method are being compared to the current status of standardisation activities. The general pattern of implemented standards follows the evaluation derived from the foresight exercise performed in 2006, making a basic assessment of the approach possible. Chapters one and five form the frame for this thesis. For a current submission both chapters have been joined to the article "Anticipating Regulatory Needs within Early Standardisation – Empirical Foundations and Concept Assessment of Standardisation Foresight".

Zusammenfassung

Trotz einer Vielzahl starker ökonomischer Effekte und Auswirkungen von Standardisierung auf die technologische Entwicklung von Innovationen, ist die Standardisierungsforschung ein recht unterrepräsentiertes Forschungsgebiet. Erst die Ergebnisse der empirischen Forschung der letzten Jahre weckten verstärkt das Interesse für die ökonomischen Funktionen und die damit einhergehenden Implikationen von Standards als auch Auswirkungen auf die Akteure des Nationalen-Innovations-Systems (NIS). Diesem Umstand ist es vermutlich zu verdanken, dass es für diesen Bereich bisher keinen systematischen Vorausschau-Ansatz (Foresight-Ansatz) zur Identifikation zukünftiger Standardisierungsthemen gab. Auch eine Betrachtung der ökonomischen und politischen Implikationen von Standardisierung, durch nationale Technology Foresight Programme, wurde bisher vernachlässigt.

Untersuchungen der bisherigen Praxis zeigen zudem, dass bisher neue Normungs- und Standardisierungsthemen durch die Mitglieder bereits existierender Normungsgremien eingebracht werden, gelegentlich unterstützt durch Einzelmaßnahmen der nationalen Normungsorganisationen. Doch gerade bei neu entstehenden Disziplinen bzw. Technologiefeldern bei denen mehrere Gremien zusammenarbeiten müssten oder neue Themen noch keine Repräsentanz in der bereits vorhandenen Gremienstruktur haben, ist neben der Identifikation von möglichen Themenfeldern und ihrer speziellen Normungsthemen auch die Identifikation und Ansprache neuer Akteuren notwendig um qualitativ hochwertige Ergebnisse erarbeiten zu können.

Die vorliegende Dissertation beschäftigt sich vor allem mit der Frage, wie ein solcher Foresight Ansatz aussehen sollte, um die speziellen Anforderungen an die Standardisierung zu erfüllen. Die Arbeit liefert einen Beitrag zur Erarbeitung eines solchen systematischen Ansatzes durch die Identifikation möglicher Methoden. Der Schwerpunkt der Betrachtung liegt auf dem Einsatz von Methodenkombination bzw. der Ergänzung etablierter Foresight-Methoden wie z. B. der Delphi Befragung mit Methoden aus der Wissenschafts- und Technologie-Indikatorik, sowie der Erweiterbarkeit durch Methoden der bibliometrischen Analyse, des Text-Minings und der Netzwerkanalyse. Zur Beschreibung der einzelnen Methoden werden meist explorative Analysen verwendet, die praktische Einblicke in die Durchführung solcher Analysen geben sollen.

Aufgrund des kumulativen Charakters dieser Arbeit kommt es in verschiedenen Bereichen zu thematischen Überschneidungen und Dopplung im Text. Zudem wurden einige Elemente des Ansatzes im zeitlichen Verlauf der Arbeit weiter entwickelt und methodisch ergänzt. Diese Dopplungen sind zum Teil der Motivation und Herleitung der Argumentationskette der einzelnen Artikel geschuldet, zum anderen wurden Überschneidungen explizit auf Wunsch der Artikel-Rezensenten (Reviewer) der einzelnen Artikel mit aufgenommen. Dies betrifft vor allem die Teile der Moti-

vation des gewählten Standardisierungs-Foresight-Ansatzes, die Beschreibung der ökonomischen Effekte von Normen und Standards und die Beschreibung des gewählten Ansatzes zur Identifikation zukünftiger Standardisierungsthemen. Trotz der Überschneidungen versucht jedoch jeder Artikel einen eigenen, unterschiedlichen Blickwinkel auf den Ansatz einzunehmen. So thematisieren die einzelnen Artikel beispielsweise einen bewertenden Ansatz, die Beschreibung der Analysen und die detaillierten Ergebnisse der Indikatorik, die eingesetzte Delphi Methode sowie Methoden zur Ergänzung des Ansatzes. Ein wiederkehrendes Element ist hierbei die Betrachtung des Technologiefeldes Nanotechnologie, das als eine Art Fallstudie dient.

Das erste Kapitel dieser Arbeit soll in die Thematik der vorliegenden Dissertation einführen. Hierbei sollen Antworten auf folgende Fragen gefunden werden: Braucht man einen systematischen Foresight Ansatz zur Identifikation zukünftiger Themen in der Normung und Standardisierung? Worin liegen Gemeinsamkeiten zu bereits vorhandenen Foresight Ansätzen? Wie sieht eine mögliche Implementierung eines solchen Ansatzes aus? Was sind alternative und ergänzende Methoden für den Ansatz? Und wie sind die Ergebnisse des Ansatzes einzuschätzen? Der Artikel adressiert somit eine ausführliche Motivations- und Anforderungsbeschreibung für einen Standardisierungs-Foresight-Ansatz. Hierbei werden mögliche Probleme beschrieben, welche sich aus der aktuellen Praxis bei der Identifikation neuer Themen in der Normung ergeben. Zur Konkretisierung des Ansatzes wird eine Abgrenzung zum Technologie Foresight Ansatz, durch eine Beschreibung der Gemeinsamkeiten und Unterschiede beider Ansätze, vorgenommen. Aufbauend auf der Motivation und dem Anforderungsprofil, werden mögliche Methoden, deren Alternativen und Erweiterungsmöglichkeiten betrachtet.

Der zweite Artikel "Identifying Future Fields of Standardisation – Methodology and Empirical Experiences" bildet das zweite Kapitel und adressiert das zugrundeliegende Modell ökonomischer Effekte von Normen und Standards und die Rolle verschiedener Normungstypen im Forschungs- und Entwicklungsprozess, er liefert aber vor allem eine detaillierte Beschreibung der Ergebnisse des Indikatorik Ansatzes sowie der Delphi Befragung für das Themenfeld Nanotechnologie. Neben der Beschreibung der generellen Methode wird zudem auf die Befragungsergebnisse zur Foresight Praxis internationaler Standardisierungsorganisationen etwas genauer eingegangen.

Der dritte Artikel "Identification of Future Fields of Standardisation – An Explorative Application of the Delphi Methodology" beleuchtet stärker den Foresight Schwerpunkt des Ansatzes. Neben der Betrachtung der Zielsetzung, werden die Voraussetzungen für einen "optimalen" Foresight Ansatz für Standardisations-Foresight hergeleitet. Der Hauptteil des Artikels adressiert jedoch die Bewertung des gewählten Delphi Ansatzes und hierbei vor allem die Bewertung der Erweiterbarkeit von Delphi Befragungen mit Hilfe von Methodenkombinationen und die Anwendbarkeit auf neue Anwendungsfelder für die Delphi Methode. Zudem werden eine Bewertung, speziell hierbei die Eignung für die Identifikation der entsprechenden Stakholder Gruppen thematisiert. Hierzu werden Haupt-Charakteristika von Interessengruppen im Normungsprozess beschrieben und eine Herleitung und Beschreibung der dazugehörigen Indikatoren vorgenommen. Der Artikel beschreibt zudem die Modifikationen der ursprünglichen Methode, welche vorgenommen wurden, um praktischen Umsetzungsprobleme zu adressieren. Weitere Komponenten sind eine vergleichende Analyse der durchgeführten Delphi Studien, eine theoretische Fundierung zu den Wissenschafts- und Technik-Indikatoren, der Delphi Methode sowie die Rolle von Normen und Standards und ihre ökonomischen Effekte.

Der vierte und letzte Artikel "Supporting Successful Standardisation Processes in Complex Emerging Fields through Quantitative Analysis – The Case of Nanotechnology", schließt die Entwicklung des beschriebenen Foresight-Ansatzes mit einer methodischen Erweiterung des in den Artikeln 1 bis 3 verwendeten Indikatorik-Teils. Neben der Betrachtung einiger Hauptherausforderungen erfolgreicher Standardisierung in komplexen neu entstehenden und heterogenen Technologien, werden hierzu eine Reihe quantitativer Methoden vorgestellt, welche die Identifikation und Integration von Themen und Forschern, in solchen Forschungsfeldern, in Standardisierungsprozesse ermöglicht. Diese bieten die Möglichkeit einer explorative Strukturanalyse für neu entstehende Technologiefelder. Durch die Identifikation vielschichtiger, komplexer Strukturen von Wissenschaftsfeldern unterstützen sie dabei Handlungsfelder für die Standardisierung aufzuzeigen. Am Beispiel des komplexen Forschungs- und Technologiefeldes Nanotechnologie werden drei mögliche Wege unterschiedlicher Detailebene betrachtet: (1) Beschreibung eines historischen Abrisses durch Zeitreihen, (2) Cluster- und Netzwerkanalyse von Co-Klassifikationen und (3) Analyse von Worthäufigkeiten und Co-Häufigkeiten von Schlüsselworten als Methoden des Text Mining.

Kapitel fünf schließt diese Dissertation mit einem Rückblick auf fünf Jahre Standardisierungsarbeit im Themenfeld Nanotechnologie. In diesem Kapitel wird eine qualitative Bewertung des Standardisierungs-Foresight-Ansatzes vorgenommen. Hierbei werden basierend auf den in 2006 gesammelten Daten, die Ergebnisse des Foresight-Ansatzes mit den aktuellen Stand an Standardisierungsaktivitäten verglichen. Dabei folgt die generelle Abfolge der realisierten Normen den Expertenbewertungen der in 2006 durchgeführten Foresight Studie, was eine generelle Bewertung des Ansatzes ermöglicht. Kapitel eins und fünf bilden den Rahmen dieser Arbeit und wurden für eine aktuelle Einreichung in einer wissenschaftlichen Zeitschrift zu einem Artikel zusammengeführt: "Anticipating Regulatory Needs within Early Standardisation – Empirical Foundations and Concept Assessment of Standardisation Foresight".

Publication and Submission Record

The chapters are based on individual papers. All papers have been peer reviewed, revised and accepted for publication. Only minor adjustments, like additional paragraphs, appendices and footnotes, have been made for this dissertation. Two of the four articles have already been published; one paper is waiting to be published. One paper is still under second round review. The order of the references reflects the order of the papers in the thesis.

Essay No 1 (chapters one and five of this thesis): The essay "Anticipating Regulatory Needs within Early Standardisation – Empirical Foundations and Concept Assessment of Standardisation Foresight" was submitted to R&D Management and is currently under second round review.

Essay No 2: The essay "Identifying Future Fields of Standardisation – Methodology and Empirical Experiences" was submitted to and reviewed by the International Journal of Technology Management (IJTM) for the special issue on "The Foresight in e-Era". After accepting the essay, it was transferred to and published in the International Journal of Foresight and Innovation Policy (IJFIP) (2011) Vol. 7, No. 4, pp. 268–310. The article is co-authored by Prof. Dr. Knut Blind.

Essay No 3: The essay "Identification of Future Fields of Standardisation – An Explorative Application of the Delphi Methodology" was submitted to, reviewed and published by Technological Forecasting & Social Change (2011) Vol. 78, pp. 1526–1541, for the special issue on "The Delphi technique: Current developments in theory and practice". The article is co-authored by Prof. Dr. Knut Blind.

Essay No 4: The essay "Supporting Successful Standardization Processes in Complex Emerging Fields through Quantitative Analysis – The Case of Nanotechnology" was submitted to and reviewed by the International Journal of Innovation and Technology Management for the special issue on "Managing Emerging Technologies: The Case of Nanotechnology". The essay is currently waiting to be published. The article is co-authored by Dr. Stephan Gauch.

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Finally, I thank Bero for his patience and critical comments, always keeping me on the ground, as well as both of our families, who always support us.

Kerstin Goluchowicz

Contents

1 Introduction to Standardisation Foresight

Abstract
This article gives rationals for a foresight approach to anticipate future standardisation activities to support the scientific and technical development of innovations. In addition to formulating general requirements for such foresight activities, which are based on the similarities to the technology foresight approach, the applicability and expandability of a possible implementation are discussed. Using a combination of quantitative and qualitative methods in this implementation, possible alternative methods are also presented, which may guide implementation of different foresight problems and application areas.

Keywords
Standardisation foresight, technology foresight, science and technology indicators, Delphi, impact analysis

Contents

1.1 Motivation and rationales for standardisation foresight

What are optimal framework conditions for innovation that support a positive economic development of a country, and how should these conditions be implemented from a regulator's point of view? A variety of scientists devote their research to this question. This question is still highly relevant, since countries or economic regions, like the European Union, are in a competitive struggle for global market shares. Mainly, increasing globalisation and growing competition caused by an increased number of international actors in science and innovation imply pressure to act on policy-makers. Motivated by this and other drivers, which are supposed to have impact on economic development, specific policy instruments are being sought to create conditions conductive to innovation. In general, it is assumed that the combination of strategic public funding and an associated regulatory framework should create good conditions for the development of technologies, profitability of domestic industries and companies, and therefore support prospects of the overall national economy.

To further deepen the view on one part of the regulatory framework in the national innovation system, our work focuses on the particular setting and effects of standardisation and their impact on science and technology (S&T). Driven by the same motivation as described above, competitive thinking also influences the initiation and funding allocation of national standardisation activities. Arguably, a lack of supporting standardisation bears the risk of delaying national technological development and adversely affects the economy of a country. This considers the argument by Tassey (1995): If standardisation or an appropriate S&T infrastructure is not in place at the right time, this could bring actors to invest in their own proprietary infrastructure, which can inhibit later standardisation efforts (Tassey, 1995). Standardisation provides mechanisms to support the transnational diffusion of domestic technology and service applications (Mansell, 1995), maintaining the competitive capacity of a country.

Even if science and technology development is only one factor for maintaining competitiveness, it is one of the main concerns of theoretical considerations and thus a key issue for national technology foresight activities. Other factors, like internationalisation, trade openness of markets, infrastructure, education, availability of skilled labour, demand, conditions for goods and services, as well as industry and firm structure may be equally important (see for example OECD (2009), Clark & Guy (1998), Porter (1990)). However, due to the fact that science and technology development can be much easier influenced by e.g. strategic targeted funding activities, technology foresight exercises focus on the identification of future fields in science and technology to support R&D and innovation policy. Due to its effects, the standardisation process is strongly linked to the science and technology development and therefore the S&T output (e.g. scientific publications and patent applications) provides information on future activities and is a starting point for "standardisation foresight" activities. This term refers to foresight activities that identify future standardisation fields and the anticipation of standard topics and standard types to support the S&T. Thus, the approach described in this paper focuses on factors associated with S&T development.

Current standardisation research theory discusses widely an important role of standardisation processes and related output, i.e. formal or informal standards, is to support the research and development process (R&D process) of technological innovation. For a detailed overview of the effects and impacts of standardisation, main points of the theoretical and empirical work by: Blind (2004); Blind & Jungmittag (2008); Clark & Guy (1998); Farrell & Saloner (1986, 1985); Gauch & Blind (2006); Hudson & Jones (2003); Jungmittag et al. (1999); Katz & Shapiro (1994, 1986, 1985); Lecraw (1984); Swann (2000); Swann et al. (1996); Temple et al. (2005) are summarised. Table 1.5 in the annex presents a collection of these economic effects and functions of standards and the standardisation process on macro and micro levels, which are acknowledged both from a theoretical and empirical point of view. Especially interested readers may also want to refer to the more general categorisation of standards by their economic effects by Blind (2004), David (1987), David & Greenstein (1990), Swann (2000) and Tassey (2000). In addition, an even more extensive overview and discussion of related research can be found in Blind et al. (2010), Gauch & Blind (2006) and Blind (2004).

This paper highlights and focuses on a number of specific effects. In short, by providing different types of standards for different stages of the R&D process, standardisation tries to link the specific stages, to set optimal conditions for further development of technologies (Blind & Gauch, 2009). These different types of standards are also linked to economic functions (Swann, 2000)[1]. The efficient market penetration of technology is also dependent on the degree and timing of standardisation activities (Tassey, 1995). Especially, the transfer of the implicit knowledge about technical details in standardisation documents (like formal standards) is an important part of the linkages between the S&T development and supporting standardisation activities. This also includes the knowledge transfer in standardisation processes itself, which is actually one main motivator for stakeholders to participate in standardisation processes (see Blind & Mangelsdorf (2010)). In addition, initiated at an early stage, the consensus-based standards should be a tool to accelerate and relieve pressure from the national regulation. This shows the value of standards as a policy instrument and has been recognised by governments, as well. In recent years more efforts to promote the transfer of research results into industry have been made specifically; with the aim of maintaining the competitiveness of the economy (see Clark & Guy (1998)). Even if this approach might provide some reasons for a debate, it is however non-controversial that the basic research has

[1] More details on this can be found in essay 2 of this thesis.

important, but indirect effects on industrial innovation.[2] This effect results in a new directed public funding towards this link (see Clark & Guy (1998)). In this specific linking of research and industry increasingly emphasis on standardisation is notable in Germany (see DIW (2010)). Here, standardisation activities are increasingly used to disseminate research results and innovation. This trend is reflected in the "Standardisation Policy Concept of the Federal Government"[3] (published in autumn 2009), the "German Standardisation Strategy"[4], and the related initiative of the federal ministry of economics and technology (BMWi), named "Transfer of research and development results through formal and informal standardisation (TNS)".

The significant value of standardisation within the regulatory framework, the effects on the technological development, and new policy trends to link research and standardisation more closely, imply that foresight activities have become highly relevant on this subject, on a national or even international level. To ensure diverse benefits of standardisation for business and society and to avoid negative effects of standardisation (e.g. lock-in effects, industry barriers or obstacles for innovation[5]), there is a necessity for systematic monitoring and early anticipation of future standardisation needs and the adoption of innovative topics in standardisation processes.

Results of a conducted survey[6] as well as discussions with representatives of companies active in German standardisation result in the following description of current practice for identifying and selecting of innovative topics in national standardisation setting:

National standardisation is driven by multi-layered interests of participating actors and stakeholders. Standard Setting Organisations (SSOs) promote participation, saying that participants can shape the development of standards and technical rules according to the participants' interests and ideas and emphasise the bottom-up nature of the process. Standardisation processes are therefore strongly influenced by strategic goals of competing companies and other organisations. In addition, the outcome of standardisation processes does not necessarily reflect superiority of alternative technologies or designs (Mansell, 1995). As Mansell (1995) observed, they often result from oligopolistic competition, conflict resolutions or are a product of a political bargaining processes of stakeholders (see Hawkins (1992), Mansell (1995, 1990) and Utterback & Suarez (1993). Innovative topics for standardisation are usually raised by members of standardisation committees. Further

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[2] Here, Clark & Guy (1998) give some additional examples: Providing information, contributing to the training of scientists and engineers, and development of new research techniques.
[3] http://www.bmwi.de/BMWi/Redaktion/PDF/M-O/normungspolitisches-konzept-der-bundesregierung,property=pdf,bereich=bmwi,sprache=de,rwb=true.pdf
[4] http://www.din.de/sixcms_upload/media/2896/DNS_english%5B1%5D.pdf
[5] See also table 1.5 in the annex.
[6] See also essay 2 for more details on this survey.

investigation[7] show 63% of ideas on standardisation projects came from people in the standards committees (17% from "outsiders" and 20% are not specified). Although, everybody can propose new topics to standardisation committees in written form, the majority of applications derive from members of established committees themselves. The same committee is then responsible for the decision of how to proceed with this topic and to initiate new activities. Since organisations and companies will be charged for committee participation, type and intensity of contribution is dependent on the resources available (which often presents difficulties for small and medium-sized companies). To attenuate this situation there is the possibility of commenting published new standardisation drafts free of charge. This option, however, usually is used by companies already active in standardisation. These selective impulses for new topics are sometimes supported by sporadic use of specific methods such as expert workshops, surveys and publication analyses conducted by participating stakeholders or members of the SSOs. But this is the exception, not the rule.

In addition, despite its long tradition, the use of systematic foresight analyses for standardisation issues were excluded from technology foresight approaches. But given the likely economic impacts of standardisation, it is however important that SSOs act as mediator having an overview of current and innovative technological developments in order to provide sufficient incentives to market participants with limited resources with respect to general participation and topic creation. A systematic foresight approach to anticipate future needs in standardisation within a given, new technology field can help balance this situation.

To produce further arguments, contrary to ever-shorter life cycles of products and technologies, the average time for developing a standard is three years (see DIW (2010)). This increases pressure on standardisation-setting processes to find an optimal timing for activities (Tassey, 1995). On the other hand this brings forth arguments for national activities at an early stage. In this way, standards can support the different stages of the R&D process more efficiently and for SSOs to be able to conduct demand-oriented resource planning. Due to the increased expectations of standardisation (e.g. as a basis for European policies and directives) and the need for coordination of increasingly complex technologies, standardisation will be increasingly a political issue. Thus, it should be subject to technology foresight, particularly because the change to a substitutive technology can cause high amounts of opportunity and adjustment costs after a standard has been implemented and the diffusion of associated products has taken place (i.e. a reduction of coexisting or competing technical solutions) (see Blind (2004); Farrell & Saloner (1986); Lecraw (1984); Swann (2000)). Moreover, according to the study of the DIW (DIW, 2010) only 20% of the published German standards in 2008 were developed in Germany. For this development globalisation and harmonisation efforts of the European Com-

[7] Results from a study commissioned by the federal ministry of economics and technology (BMWi).

munity are especially decisive. Although standardisation activities are increasingly carried out on European and international level, they still have to be identified and initiated nationally, in order to represent national interests. European and international standardisation processes are based on a principle of national delegation of mirror committees of national SSOs. Standards developed at European level have to be transferred into national standards. In contrast, the adoption of international standards into national standards is voluntary. The costs for a delay in international participation can be high, especially if standards are not optimal for the domestic industry and derive from foreign competition (Tassey, 1995). This further supports the idea that systematic foresight activities to strengthen national standings in science and industry should be implemented.

1.2 Outline for standardisation foresight

This section outlines the basic requirements for the development of a standardisation foresight approach.

As outlined in section 1.1, the increasing internationalisation of standardisation has further implications than one might suspect at first. Not only has the relocation of standardisation an impact on the global markets, but they also significantly influence national standardisation policies. Due to the adoption of international standards into national body of standards, national framework conditions that are less subjected to national policies influences are created. To actively participate in international standardisation activities, it is therefore necessary, in addition to the identification of innovative topics, that high-quality proposals for the implementation of these topics (compiled in national committees) can be contributed. However, this requires national preparations. Otherwise, i.e. with missing or poorly prepared proposals, other superior proposals for implementation can prevail at international level, which in turn can be detrimental to the domestic industry. To be successful in international standardisation, however, the "right" players have to be committed to the international level.

Therefore, a standardisation foresight approach should have two main components: (1) A subject search, which considers both the S&T development and community issues, allowing an assessment of maturity, and (2) the search for key players in these areas.

This raises the following questions. Does the technology foresight approach provide methods suitable for this concept and what are parallels and differences of the standardisation foresight and technology foresight approaches? To answer these questions and to give some background on this topic, a literature review on technology foresight is given. A comparative discussion of both approaches will be discussed in the following.

For an introduction, Salo & Cuhls (2003) and Georghiou (2003) use both fairly accurate descriptions of technology foresight. They characterise technology foresight at a national level as:

> A strategic policy instrument (Georghiou, 2003), which seeks to generate an enhanced understanding of possible scientific and technological developments and their impacts on economy and society, in order to support the shaping of suitable science and technology policies (S&T policy), the alignment of research and development efforts with social needs, the intensification of collaborative R&D activities and the systemic long-term development of innovation systems (Salo & Cuhls, 2003).

To point out common aspects of the two approaches, some of the basic objectives of technology foresight are summarised. A literature review reveals that the technology foresight approach has undergone fundamental changes in the last years of his application. Initially it was used for most accurate predictions about future developments of technological change in the form of forecasts. Recent studies show new rationales for national technology foresight programs (Martin & Johnston, 1998). Mainly, large-scale national foresight programs were carried out (see Georghiou (2003); Martin & Johnston (1998) and Miles (2010)), which assess respective national strengths and weaknesses to provide studies of research and innovation plans to priorities in national funding in the light of such potential long term future developments (Martin & Johnston, 1998; Miles, 2010).

According to Martin & Johnston (1998), different drivers are responsible for this development. This includes, as already described in the first section, an increased economic competition caused by a dramatic increase in the number of relevant players. As examples they give the economic liberalisation of China and other political and economic developments in East Asia and Eastern Europe, which cause increased innovation pressure due to the different price levels, for example in labour costs. They further argue, that consequently science and technology will gain more importance to maintain economic growth (see Martin & Johnston (1998)), since it is assumed that active promotion and funding of science and technology can have significant impact on the economic development. On the other hand, increased pressure on government (i.e. political pressure to balance the public budget) caused by social trends like an ageing society lead to a decrease of public funding (Martin & Johnston, 1998). This affects not only measures of public funding directly, but equally influences technology foresight activities to choose between competing science areas and technologies thus successfully linking S&T closer to the nation's economic and social needs (Martin & Johnston, 1998). This mainly concerns activities that support national strengths. Last but not least, growing transdisciplinarity and heterogeneity in science and technology lead to an increased need for networking and collaboration in science and research (Martin & Johnston, 1998).

With this description of drivers and impacts, Martin & Johnston (1998) refer to important direct objectives and functions of national technology foresight programs, also indicated in other papers (see Amanatidou & Guy (2008); Anderson (1997); Georghiou (2003); Martin (1995); Martin & Johnston (1998)) like:

(1) Identification of future opportunities preferably in generic research topics and technologies, and infrastructure for innovation (e.g. financial, fiscal and regulatory structures, education, career development, buildings and equipment), which have the potential for widespread application across industrial sectors to set or determine priorities for investment in science, technology and innovation activities (see Georghiou (2003); Martin & Johnston (1998); Martin (1995) and Anderson (1997)).

(2) Reorientation of the science and innovation system (see Georghiou (2003)).

(3) Demonstration of the vitality of science and innovation system, e.g. identification of technological opportunities and assessment of the capabilities of science and industry (see Georghiou (2003)).

(4) In addition, many authors especially point to the networking function of foresight. Foresight can stimulate communication and forge new partnerships between different stakeholders, such as scientists in public research establishments, people who work in government or industry, and research funders (see Amanatidou & Guy (2008); Anderson (1997), and Martin & Johnston (1998)).

(5) Involvement of new actors and stakeholders to widen the range of actors engaged in science and innovation policy (see for example Martin & Johnston (1998) and Georghiou (2003)).

(6) Development and evolution of strategies to cope with negative consequences of future developments (see Amanatidou & Guy (2008)).

Foresight in general, also facilitates hidden indirect benefits and functions like e.g. mutual learning effects and knowledge generation (Amanatidou & Guy, 2008). Here the participants can learn from each other through exploration and analysis of issues in science and technology (Anderson, 1997) which can foster the development of multidisciplinary in research and facilitate an informed public (Amanatidou & Guy, 2008). Joined decision-making (Amanatidou & Guy, 2008) by generating a consensus (Anderson, 1997; Martin, 1995) amongst participants, also encourages a sense of ownership of the findings and gains commitment among the partners to act on these findings (Anderson, 1997), and thus, enforces the active engagement of relevant actors (Amanatidou & Guy, 2008). This facilitates the diffusion and absorption (Amanatidou & Guy, 2008) of national priorities among diverse groups as well.

But generally, the process is believed to have more of an impact than a future strategy development or any list of priorities which are the obvious product of foresight (see Anderson (1997)), i.e. the networking and indirect effects of foresight. Because foresight programs enhance collaboration and networking between the involved organisations, it can improve conditions for successful innovation (see Amanatidou & Guy (2008)). Amanatidou & Guy (2008) argue further that economic development is dependent on technical innovation and the degree of collaboration and networking in society.

For identifying relevant actors, the national innovation system (NIS) is often used (see Arnold et al. (2001)). For policy-makers, it can be especially helpful to identify leverage points for enhancing innovative performance and the networking among actors and institutions (Martin & Johnston, 1998; OECD, 1997). Foresight activities can give better understanding of these linkages, to gain more information and to improve the technological performance (see Martin & Johnston (1998)).

Basically, standardisation foresight applies to the same considerations as major national foresight programs. On this, the general aim of technology foresight is also very similar. So one could argue the approach in demand represents a special case of a technology foresight approach. But there are some differences between the two approaches.

In general, main reasons for implementing technology foresight activities are, according to Martin (1995), the selection most promising research areas with greatest economic benefits. This holds true for standardisation foresight as well. If each of the objectives of technology foresight is considered, standardisation foresight approach aims for similar targets. In particular this applies to the goals one, two and three (i.e. identification of future opportunities, reorientation of the science and innovation system, and identification of technological opportunities and assessment of the capabilities of science and industry[8]). In the German case, since the standardisation foresight approach emerged from a program to strengthen the national standardisation, it has pursued the objective to highlight national strengths and take key technological fields of the German High-Tech Strategy 2010 of the federal government into account. In addition, objective five, i.e. the involvement of new actors and stakeholders, is covered. The approach should allow the identification of key stakeholders for a chosen subject area, including actors not yet involved in standardisation.

An important function, foresight networking, however, can be neglected by the chosen approach, because standardisation itself is understood as a networking tool, bringing together all essential stakeholders. This is also confirmed by consideration of the motives for stakeholder participation in standardisation. Specifically, increased opportunities for cooperation with new partners, is a strong motive for

[8] See text above for reference information.

many actors to take part in standardisation processes (see Mangelsdorf (2011)).

1.3 Standardisation foresight approach

In this section the implementation of the chosen foresight approach for identifying future standardisation issues will be briefly presented, i.e. core methods are outlined. It should be noted that the chosen approach describes only one of the plausible ways of conducting standardisation foresight. Therefore, in addition to the description of the core methods, supplemental short descriptions of alternative methods, including methods for more refined, in-depth analysis such as bibliometric analyses, text mining and network analysis are discussed to extend the core approach.

1.3.1 Main methods

The main approach includes a combination of quantitative analysis of indicators that help identify dynamic S&T fields and in-depth online Delphi surveys for evaluating future topics in such fields. It is complemented by some additional methods for identifying experts and future topics. It should provide a systematic approach for a neutral assessment, defined in contrast to the rather selective and subjective generation of topics among standardisation committee members. In addition, it contains the possibility of integrating new stakeholders, i.e. new impulses for standardisation processes.

Basically, the indicator approach tries to identify potential trends in growing S&T fields, using an extended set of S&T indicators[9] to characterise the different activities in the stages of the R&D process. Taking a policy perspective on standardisation processes into account, the analysis centers on the identification of comparative advantage and technological opportunities of the national science and innovation system, assessing the capabilities of domestic science and industry, thus new standardisation activities can support and enhance the NIS' capacity. Here two indices were calculated, which allow comparison between S&T fields amongst countries over time at various levels of detail (i.e. from macro to micro level, including analyses for identifying global trends and detailed analyses of topics and actors). First, the Revealed Comparative Advantage (RCA) (see the basic form by Balassa (1965) as a measure of national specialisation compares the national and international activities in one field related to the national and international activities of all fields. Second, Sharpe ratios (see Sharpe (1998)), as a measure for the field dynamics, compare growth rates for specific fields in relation with activities world-wide.

[9] E.g. scientific publications and patent applications which are also used for other types of S&T-based technology foresight studies. More details on the indicator set are given in section 1.3.2 and in essay 3 of this thesis.

Scientific publications and patent applications are especially useful indicators because of their additional bibliometric data. As the next step of the approach this data allows identification of experts in the identified fields. They also provide data for more detailed analysis like text content analysis, which can be used to determine particular future standardisation topics in combination with a qualitative, in-depth literature survey.

Because the anticipation of future standardisation needs to support the stage of R&D process in the identified fields, a sub-sequential Delphi survey is used. Here, dimensions like timing of standardisation, importance, type of standard and standardisation level (e.g. national, European or international level) were assessed by the experts identified, resulting in a prioritised listing of standardisation topics.[10] The evaluation of the responses of the standardisation topics provided additional information, such as disagreements among experts. This may help assess the current stage of technology development and indicates whether standard establishment can provide further technical support or should be used for knowledge and technology transfer. In addition, disagreement signals an increased need for discussion among the actors in the community.

1.3.2 Method alternatives and expansions

As already described in the above subsection, the approach is only one of the plausible combinations of methods. The following tables 1.1–1.4 demonstrate complementary and additional methods, divided in actor- and theme-centred steps. These methods also provide extensions of the approach related to other issues of technology foresight. The individual method modules can be combined according to the foresight question and thematic field considered.

Besides the quantitative statistical analysis of database data, qualitative analysis of external study, and any form of expert input can be used to identify national strengths and field dynamics in the first step (see table 1.1).

For quantitative or even qualitative analyses the following set of indicators can be used. The first category summarises S&T indicators for scientific and technological change, such as scientific publications (characterises the activities in basic or fundamental research), patent applications (characterises activities in applied research and development or technological performance of companies (see OECD (2009)), and trademark applications (characterises activities for product market launches and services innovations and companies). In the second category an indicator for global markets includes foreign trade data (characterises activities in export). The third category combines indicators for governance and infrastructure: Standard publications (characterises the demand of standardisation activities), pub-

[10] For more details see essay 3.

lications of regulations (characterise complementary framework items, describing also complementary need for standardisation), publications of public procurement processes (characterises another level of the demand perspective on which standards can foster diffusion), and public funding activities (characterising financing of R&D and thematic policy priorities). The fourth category combines more qualitative indicators for society and innovative acting, including general innovation constraints and technology acceptance (characterises uncertainty on the demand side and potential areas for standardisation activities).

Table 1.1: Complementary and additional methods for step one: Identification of national strengths and dynamic developments.

	Input	Output	Strengths / weaknesses
Quantitative indicator analysis[1]	Data, e.g. scientific publications and patent applications	• Simple time series analysis • Comparison on country level • RCA and Sharpe ratios to describe national specialisation and dynamic of fields	• Unbiased data • Limitations of data availability • Requires statistical experience
Qualitative desk research[1]	External studies and surveys	• National prioritisation and identified new fields	• Allows a quick overview • Eventually time consuming • Limitations of data availability • Risk for subjective biased results
Expert surveys[1], expert interviews[1] and expert workshops[1]	Questionnaire design, interview guide and workshop concept	• Expert opinion on national prioritisation and new fields	• Requires method knowledge not technical expertise • Eventually time consuming • Risk for subjective biased results

[1] complementary method
[2] additional method

In addition to bibliometric analyses of database data, a number of actor-centred methods for identifying different actors and experts exist, including network analysis of e.g. co-publications and citations (also using database data), a qualitative internet or desk research, expert surveys or interviews, and snowball-like approaches (see table 1.2). For the last three methods, however, there is a need for at least some knowledge of experts in advance.

Table 1.2: Complementary and additional methods for step two: Identification of actors, stakeholders and experts.

	Input	Output	Strengths / weaknesses
Bibliometric analysis[1]	Data, e.g. scientific publications and patent applications	• List of experts and their affiliations related to the topic	• Large amount of available data • Use of special software is needed • Eventually high effort for data cleaning
Network analysis of co-publications and citations[2]	Data, e.g. scientific publications and patent applications	• List of experts and their affiliations related to the topic	• Large amount of available data • Eventually use of special software is needed
Qualitative desk research[1]	External studies and surveys	• Experts and/or organisations related to the topic	• Allows a quick overview • Eventually time consuming • Limitations of data availability • Risk for subjective biased results
Expert surveys[1], expert interviews[1] and snowball approaches[1]	Some experts or other contact persons	• Experts and/or organisations related	• Requires method knowledge not technical expertise • Eventually time consuming • Risk for subjective biased results

[1] complementary method
[2] additional method

For the identification of future topics, qualitative desk research or expert surveys, interviews and workshops can be implemented. Impact analysis, historical outlines of the development of a field, cluster- and network analysis of classification or even text mining approaches give additional information for assessing the development of topics and actors in a given field (see table 1.3).

Table 1.3: Complementary and additional methods for step three: Identification of future topics in identified fields.

	Input	Output	Strengths / weaknesses
Historical outlines[2]	Data, e.g. scientific publications and patent applications	• Outline of the historic development of a field	• Unbiased data • Limitations of data availability • Requires statistical experience
Cluster- and network analysis of classification[2]	Data, e.g. scientific publications and patent applications	• Development of a field and connections or overlap with other fields	• Large amount of available data • Requires statistical experience • Eventually use of special software is needed
Text mining[2]	Data, e.g. scientific publications and patent applications	• List or cluster of Keywords	• Large amount of available data • Use of special software is needed • Eventually high effort for data cleaning
Qualitative desk research[1]	External studies and surveys	• List of potential future topics	• Allows a quick overview • Eventually time consuming • Limitations of data availability • Risk of subjective biased results
Impact analysis[2]	External studies and surveys	• List of potential future topics and connections between them	• Allows systematic analyses • Eventually time consuming • Eventually use of special software is needed • Limitations of data availability • Risk of subjective biased results
Expert survey[1], expert interviews[1], expert workshops[1]	Some experts or other contact persons	• List of future topics	• Requires method knowledge not technical expertise • Eventually time consuming • Risk of subjective biased results

[1] complementary method
[2] additional method

For the last step there are mainly two complementary methods for evaluating future topics: Delphi survey (as a special form of expert surveys) as well as expert interviews and workshops, and the road mapping approach (see table 1.4).

Table 1.4: Complementary and additional methods for step four: Detailed evaluation of future topics.

	Input	Output	Strengths / weaknesses
Delphi survey[1] (as a special form of an expert surveys), expert interviews[1], expert workshops[1]	List of topics and list of experts	• Evaluation and prioritisation of future topics	• Requires method knowledge not technical expertise • Eventually time consuming • Risk of subjective biased results
Roadmap[1]	List of topics	• Evaluation and prioritisation of future topics in form of a roadmap	• Allows systematic analyses • Eventually time consuming • Risk of subjective biased results

[1] complementary method
[2] additional method

In the following chapters the concept and cases for the standardisation foresight approach are discussed. On this different aspects of the approach are discussed and methods are put into use.

Table 1.5: Overview of some economic effects and functions of standards and the standardisation process.

Effects / functions	Description and corresponding authors
Diffusion of knowledge / Knowledge and technology transfer	Standards can promote a fast and efficient diffusion of knowledge (Blind & Jungmittag, 2008; Clark & Guy, 1998; Jungmittag et al., 1999; Swann, 2000; Temple et al., 2005); standards and the standardisation process are a form of knowledge and technology transfer (Gauch & Blind, 2006; Mansell, 1995); they provide accepted methods of producing information, e.g. measurement data for process control (Tassey, 1995)
Cost reduction	Standards can reduce transaction, search and information (Blind, 2004; Lecraw, 1984; Swann, 2000) as well as production costs (Mansell, 1995)
Mass production	Standards can reduce the size and cost of inventories; reducing the number of different shapes and sizes of products; promote economies of large-scale operation (Lecraw, 1984)
Reduction of information asymmetries	Standards can reduce information asymmetries
Signalling	Standards signal quality or safety requirements to customers, intermediaries users or consumers (Blind, 2004; Gauch & Blind, 2006; Lecraw, 1984; Swann, 2000; Tassey, 1995); especially if health, safety and welfare implications cannot be determined by users themselves (Lecraw, 1984); here national standards have more effect on the home market / international standards have more effect on foreign markets
Trade promotion	International standards have a trade promoting impact (Blind & Jungmittag, 2005; Lecraw, 1984; Mangelsdorf, 2011; Mansell, 1995; Swann, 2000; Swann et al., 1996) and affect openness to trade (Lecraw, 1984)
Competitive advantage / market organisation	Standards can create a competitive advantage for firms (Hudson & Jones, 2003; Lecraw, 1984; Lyytinen & King, 2006); national or international harmonised standards can create a competitive advantage (Hudson & Jones, 2003); standards can be used to organise markets (Blind et al., 2010); they affect the distribution of production and suppliers (Lecraw, 1984)
Product variety	Standards reduce the product variety (Farrell & Saloner, 1986; Lecraw, 1984; Tassey, 1995) by reducing of the amount of coexisting or competing solutions, leading to economies of scale (Blind, 2004; Swann, 2000; Tassey, 1995); they have also an impact on technology selection, and have stabilisation effects (Clark & Guy, 1998), thus shape technical trajectories (Swann, 2000); Compatibility and interface standards can increase variety of systems products (Blind, 2004; Gauch & Blind, 2006; Swann, 2000)
Design	Standards can influence product configurations, e.g. technical design criteria (Mansell, 1995)
Communication and coordination	Standards create a common language not only for potential trading partners (Gauch & Blind, 2006); they coordinate the next stage in the innovation process (Gauch & Blind, 2006)
Impact on growth of economies	Standards have an economic impact on growth of economies (Blind & Jungmittag, 2008; Jungmittag et al., 1999; Temple et al., 2005)
Market failure	Standards can create or correct (e.g. in form of mandatory standards incorporated into legislation or regulation) market failure (Lecraw, 1984); they can be used for correction for adverse selection (Blind, 2004; Gauch & Blind, 2006; Swann, 2000)
Entry barriers	Standards can build or reduce (e.g. in form of compatibility standards) entry barriers for industries; lock-out suppliers or producers (Mansell, 1995)
Price of products	Standards can have effects on product price (Lecraw, 1984)
Network effects	Standards can have network effects i.e. positive returns to adoption (**?**Farrell & Saloner, 1985; Katz & Shapiro, 1994, 1986, 1985; Mansell, 1995); or correct negative externalities of production and consumption (Blind, 2004; Gauch & Blind, 2006; Lecraw, 1984; Swann, 2000)
Lock-in effect	Standards can cause or avoid (e.g. through compatibility standards) lock-in effects (Blind, 2004; Gauch & Blind, 2006; Lecraw, 1984; Swann, 2000)
Risk reduction	Standards reduce risks and uncertainty for producers and consumers (Clark & Guy, 1998; Lecraw, 1984)

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2 Identifying Future Fields of Standardisation – Methodology and Empirical Experiences

Abstract

The paper describes the methodology for standardisation foresight, developed for the German Institute for Standardisation e.V. (DIN), to systematically identify innovative standardisation topics by involving the science and research community. Until now, formal standardisation bodies have not undertaken systematic efforts to conduct these kinds of foresight studies. This approach identifies future standardisation aspects in dynamic, innovative fields of technology by combining a computerised quantitative analysis of science and technology indicators (e.g. patent applications, scientific publications, etc.) and Delphi-based surveys. To illustrate the general methodological approach, this paper provides a detailed description of the results of the indicator approach and the Delphi survey in the field of nanotechnology.

Keywords

Standardisation foresight, Delphi, science and technology indicators, nanotechnology.

Contents

2.1 Introduction

Most computer-aided foresight and forecasting methods pursue a descriptive approach based on retrospective data, to adjust from the past into the future. New tools and further methodological improvements enable extensive analyses based on large data sets. This paper introduces a method, which combines online qualitative Delphi surveys with quantitative analyses of indicator data to describe activities in science and technology. In order to identify potential trends for knowledge-based standardisation, information retrieval and text mining methods are implemented using text filters and thesauruses to analyse the database data, and apply a bibliometric author analysis to identify experts. By engaging relevant actors from research to contribute to the assessment of future standardisation processes, the aim is to achieve an integration of R&D and standardisation activities.

The example of nanotechnology shows that a country's R&D leadership in a specific scientific and technological field does not necessarily translate into timely and successful standardisation activities in the latter, which may in turn affect the technical success of this country. Although Germany has occupied one of the top research positions worldwide in the field of nanotechnology science over the last few years, it has failed to transfer this excellent starting position into the leading position in standardisation initiatives (Blind & Gauch, 2009), unlike other countries or European and international standardisation organisations, which launched standardisation initiatives much earlier. More specifically,Blind & Gauch (2009) provide empirical evidence for a time lag between the German research activities and its standardisation efforts in relation to the initiation of standardisation activities in the USA or the UK.

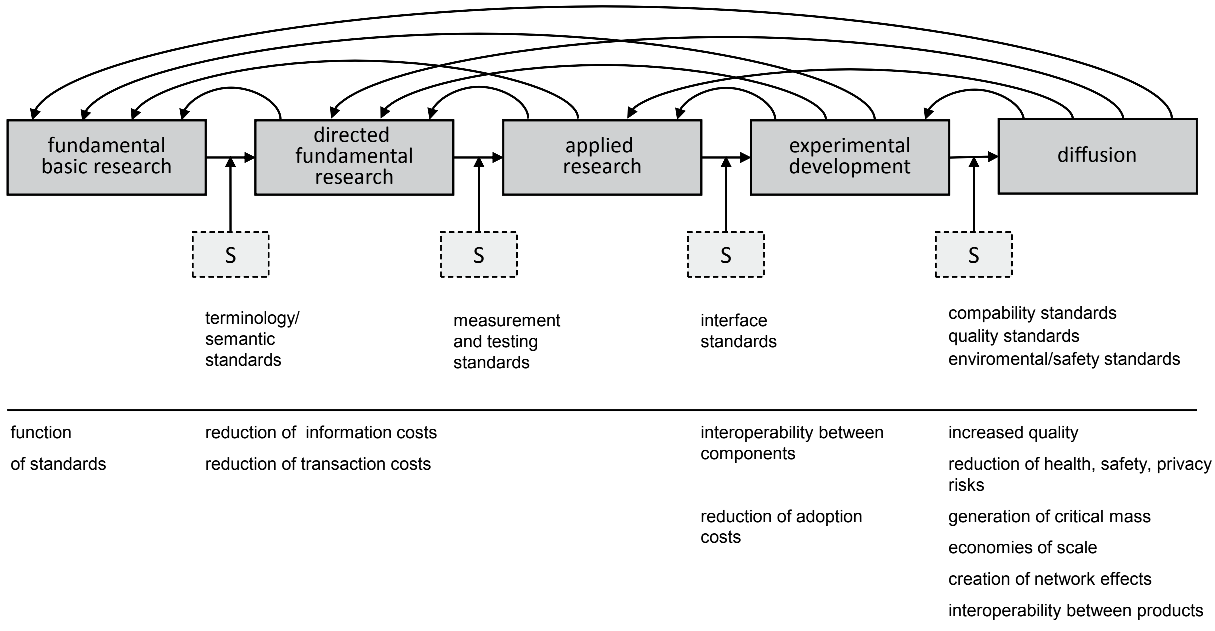
The method and some of the findings of the foresight approach developed for the German Institute for Standardisation e.V. (DIN) in the context of the INS project (Innovation with Norms and Standards) for identifying future fields of standardisation are presented, by outlining one possible way of conducting standardisation foresight. First, science and technology indicators to evaluate and "predict" scientific and technological developments are applied so that the results can be used for informed judgements on future resources and strategic decisions. The next step is a Delphi survey, which identifies particular thematic standardisation subjects, the shape of future standardisation types and demand structure.

This paper is organised in the following way: Section 2.1 briefly describes some economic effects of standardisation and provides a preliminary survey on foresight approaches in international standardisation bodies. It also includes the conceptual background and provides rationales for standardisation foresights. Section 2.2 gives a detailed description of the methodology, introduces a set of indicators and provides the results of the indicator-based approach. Section 2.3 describes the Delphi survey using nanotechnology as an example. Section 2.4 discusses the chosen approach regarding its advantages and disadvantages and gives recommendations for future studies.

2.1.1 Standards and innovation

Standards play an important role in the R&D process of technological innovations. As described by Blind & Gauch (2009), different types of standards are linked to specific stages in the R&D process. For investigating new technologies, terminology standards are required in basic research to allow or facilitate efficient communication within the research community. But they also play a crucial role in the transfer of knowledge from basic to oriented basic research and applied research. In addition to this, measurement and testing standards are needed for this transfer, and allow progress towards product-related developments. Interface standards bridge the gap between applied research and experimental development of new products and processes, which allow the interoperability of components integrated into the product or process technology. They are also essential for the diffusion of innovation in network applications. Compatibility standards facilitate the transition of prototypes into mass markets and ensure the interoperability between products. Finally, quality standards guarantee that products comply with minimum safety requirements. Figure 2.1 shows the different roles of standards in the research and innovation process.

Figure 2.1: Standards in the research and innovation process (Blind & Gauch, 2009).



The model integrates various phases of standardisation and shows how different types of standards are linked to specific stages in the R&D process. According to

Swann (2000), all these different types of standards are linked to economic functions. For instance, terminology or measurement and testing standards can lead to higher expected profits due to significant reduction in transaction costs or returns to scale may lead to higher or even additional R&D investment etc. or at least help assure returns on investment. This can have an impact that, in the case of international or European standards, exceeds national boundaries.

According to Blind (2004), product and process innovations must be successfully positioned in the market and diffused to trigger significant, positive economic effects. A functioning standardisation system can foster this diffusion. Quality standards can help to foster diffusion by solving the problem of subjective definition of quality and by defining fundamental points of the quality (Liphard, 1998; Blind, 2004). Blind (2004) argues that products and process innovations, which fulfil minimal requirements of the currently valid formal quality and safety standards, are facing lesser market risks on principle. Standardised products provide fewer information asymmetries in product characteristics and quality and, therefore, consumers are more trustful and willing to pay more (Blind, 2004). Consequently, there is a greater probability of market acceptance of new products. Foss (1996) also states that specific standards for production routines give buyers an indirect possibility of comparing different sellers' products, because they can just compare the standards.

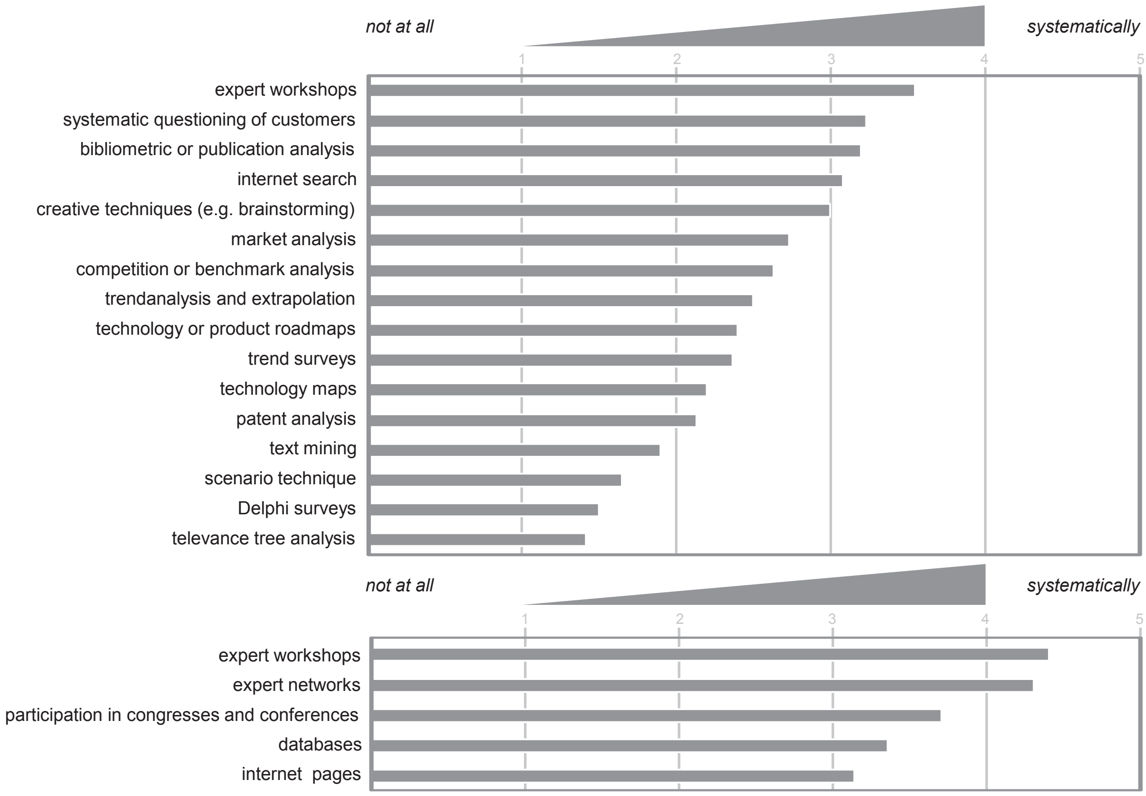
In addition, standardisation opens up possibilities for mass production, reduces the costs and thus the price, thereby enlarges the potential circle of consumers with additional advantage on R&D activities (Blind, 2004). Transaction costs also play an important role in the development and diffusion of products (Foss, 1996; David, 1987). Blind (2004) states that technical standards can exert influence on technical change in various ways. Existing standards may compete with new technologies and products, which are more familiar to the user. They can reduce the variety of technological possibilities, i.e., limit the diversity of products and thus consumer choice and exclude customers' individual wishes (Wölker, 1996; Blind, 2004). Inflexible and false standardisation can cause the cementing of the state of technology, or a lock-in of a once attained level of technical development (Blind, 2004; Lukes, 1968).

On country level, the inclusion of technology in international standards that is originated in a given country can lead to increased trade. This can provide, through effects of stabilisation into technological paradigms, long-term benefits for a country in terms of technological leadership. Consequently, the specific benefits that relate to the country level should be influenced by those technologies that are included in standards, especially when these standards are produced on the European and international level. Standards and standardisation thus become a policy issue.

2.1.2 Foresight measures

There is a long tradition of prospective studies to identify promising future fields in science and technology to support R&D and innovation policy. These have mainly been conducted by national research funding bodies (Blind et al., 1999). However, standardisation bodies have not yet engaged in frequent or systematic foresight studies. To develop a suitable approach, foresight and forecasting methods for identifying innovative technological developments were analysed and their applicability for finding future fields of standardisation were examined. In addition, a survey on the forecast activities of representatives of 14 European national standardisation bodies in a CEN working group (CEN/STAR) was conducted, which addressed the interface between research and formal standardisation as to the use of common foresight methods and other information sources. Figure 2.2 outlines the findings and shows that the most common methods for identifying recent standardisation aspects are: Expert workshops, systematic questioning of customers, bibliometric analysis and publication analysis, internet search and creativity techniques. Expert workshops and expert networks are the main information sources. The application of the rarely used Delphi surveys involving the science and research community, in combination with the indicator-based method as described in this paper, is a new approach and a methodical extension to the commonly applied methods.

Figure 2.2: Survey results among members of the CEN/STAR board. Upper diagram: Application of foresight methods for identifying future standardisation fields. Lower diagram: Use of information sources (N=28 in 14 countries).



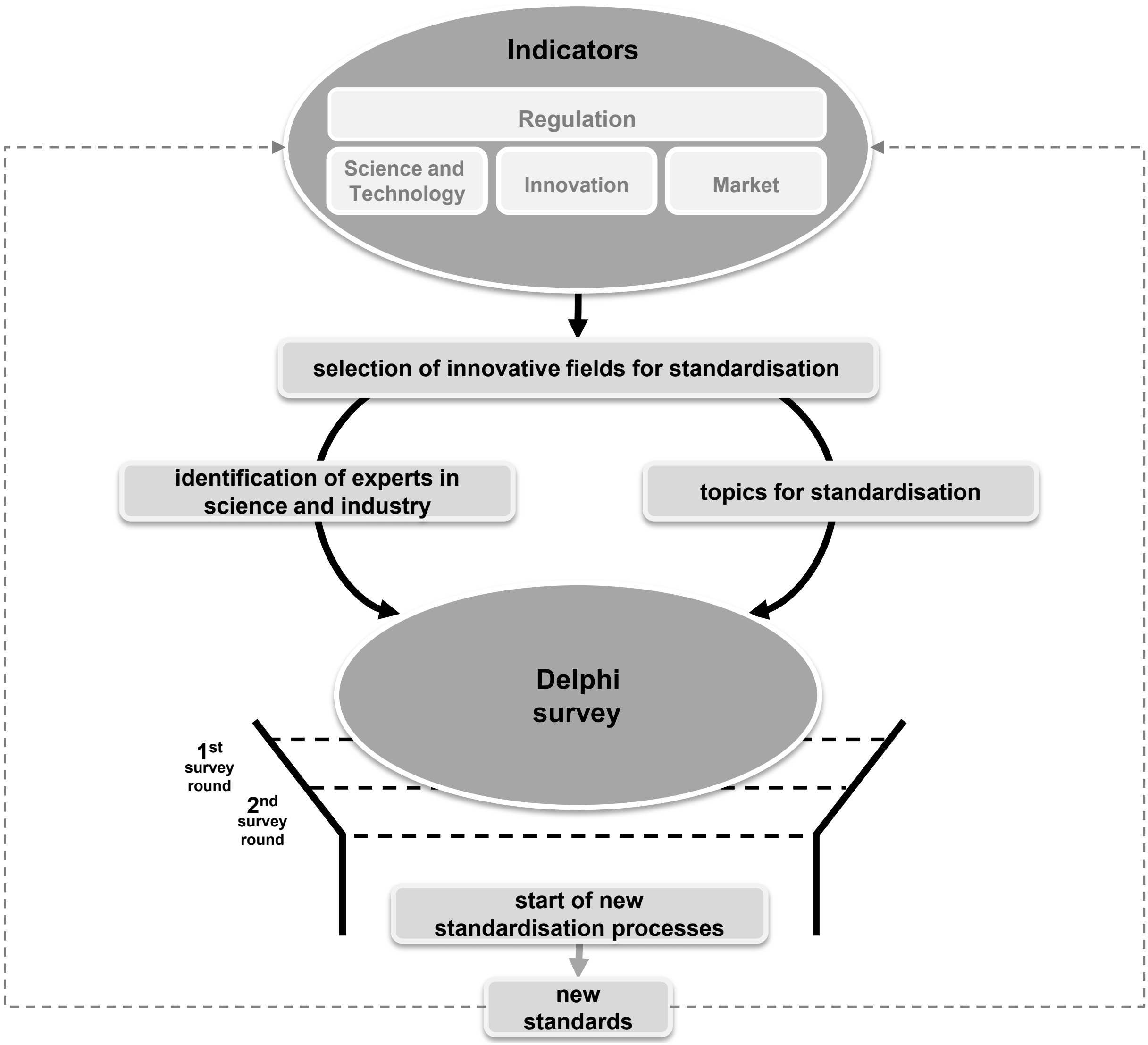
2.1.3 Method and conceptual background

R&D policies that aim to foster standard-driven innovation can be informed by methods of foresight to identify future fields of standardisation that take recent developments in science and technology into account. In the particular case of emerging technologies that hold the promise of large benefits in the future, timelines of standardisation become important. The close interaction between research and standardisation, especially in fields of emerging technologies, and the importance of different types of standards require an integrative and proactive foresight approach. However, from our point of view, simple quantitative approaches and the application of only one foresight method are not sufficient considering the different complex facets and the trajectories of technological change and the multiple functions of standards in the research and innovation process. The combination of the quantitative indicator-based approach and the qualitative analysis of the technological development plus Delphi survey improve the findings of the survey. More precisely, the identification of future stakeholders or future standard users in emerging fields further increases the effectiveness of the Delphi method applied.

For some methodological background, our method is based on a conceptual approach to determine standardisation demands in the innovation life cycle or their diffusion models, and the role of different types of standards in the research process as described in Section 2.1.1. Here, reference is made to the so-called linear model of innovation – which models knowledge flows in a relatively straightforward manner and proceeds from basic and applied research through product development to innovations marketing and diffusion in a relatively straightforward manner (Salo & Cuhls, 2003; OECD, 1997). Here, an increase in scientific inputs will directly increase the number of new innovations and technologies (OECD, 1997) in a sequential manner (Clark & Guy, 1998). Although the innovation process is the result of complex interactions between actors in the innovation system and feedback loops between the stages (OECD, 1997) and the widely recognised limitations (Martin & Johnston, 1998) and abandonment of the linear model in favour of more complex models (Salo & Cuhls, 2003), the model, however, is a good tool to investigate and simplify the mechanisms of standards in the innovation process. Furthermore, to typify the different activities in the sequent stages of the R&D process a system of science and technology indicators (see Grupp (1997)) and further indicators is used to identify growing fields of science and technology. Assuming close dependencies between research and innovation capabilities, these growing and dynamic fields require future standardisation work. Some parts of this characterisation of the underlying economic assumptions and theoretical basic principles are discussed in Blind (2008) and Blind & Gauch (2009), who give further theoretical background.

The method presented in this paper is based on a combination of the analysis of science and technology indicators plus further indicators and online expert Delphi surveys. In the first step, two basic indicators (i.e. patent applications and scientific publications) and several further indicators were analysed. Through statistical analysis of these innovation indicators, future growth fields in science and technology are identified, in which Germany could achieve the forerunner position, and in which future demand for standardisation is more likely to develop. Since research activities ideally precede standardisation activities, corresponding indicators could act as an early warning system for standardisation demands in emerging science and technology fields. Next, detailed Delphi surveys are carried out, analysing specific standardisation types required for emerging technical issues. Bibliometric data derived particularly from patent application and publication analysis allowed us to identify experts, such as scientists, inventors, research facilities and innovative companies related to these specific fields. Figure 2.3 presents the generic structure of our approach. The following sections describe each part in detail.

Figure 2.3: Chosen approach for the identification of future fields of standardisation.



2.2 Set of indicators

In the following section, the results for the indicator-based approach are we introduced, summing up the different indicators in four major categories: Technological change, global markets, governance and society and innovation (see table 2.1).

Table 2.1: Overview of the investigated indicators.

Technological Change	Global Markets	Governance	Society and Innovative Acting
• scientific publications • patent applications • brand applications	• external trade data	• standard publications • publications of regulations • publications of public • procurement applications	• general innovation constraints • technology acceptance

The underlying system of science and technology indicators spans two dimensions. The categorisation of several R&D activities runs from fundamental or basic research, applied research to experimental development up to standardisation and market launch. These sorts of activities are related to different stages of innovations, such as idea generation, conceptual design, final design, engineering and diffusion, up to imitation. In addition to the different activities and stages, input and output indicators are distinguished (see Grupp (1997)).

Table 2.1 gives an overview of the selected indicators. The first category lists important bibliometric indicators (or output indicators) to describe technological development and change. These include publications in scientific journals to characterise the activities in basic or fundamental research, patent applications, which cover the performance in applied R&D, and trademark applications as an indicator for the market launch of not only product and services innovations but also companies. The second category covers indicators to specify global markets and includes macro data, e.g. foreign trade data. The third category brings together governance indicators, such as publications of existing standards for basic evaluations of the demand, publications of regulations and the regulatory framework, i.e. the complementary standardisation need on the policy side and publications of public procurement applications to extend the demand perspective. The fourth category comprises survey-based society indicators, such as general innovation constraints and the technological acceptance on the demand side, i.e. the consumers.

Patent applications and scientific publications are particularly suitable to identify dynamic and innovative technology fields and to track changes in science and technology developments. The next section of this paper describes the development of these two basic indicators as well as the technological acceptance and publications of existing standards to illustrate the specific conditions for the field of nanotechnology.

The statistical analysis of these indicators allows the comparison between science and technology fields among countries over time (see Blind (2008)). Because one can generally find major growth for almost every indicator in all countries, absolute ratios are only partly significant. Therefore, comparative rates are calculated as a measure of specialisation (e.g. for German research activities). The absolute numbers of applications or publications are then related to the international situation. If the German research profiles are compared with international activities, the intensity of Germany's role in this research area could be seen (see formula (1)). By matching the comparative rates to the Sharpe Ratios (see formula (2)), measuring the growth for specific fields according to the respective classification, the ratio presents dynamic fields with relatively – in comparison with the worldwide activities – high rates and high Sharpe Ratios adjusted by the field size.

To summarise, to capture the overall evolution of a scientific field, we look at the aggregate changes in this field as a whole by decomposing the overall trend into smaller thematic subfields, which can then be monitored in terms of their relative importance. Even though it is arguable whether the application of classifications, such as the International Patent Classification (IPC) or the Subject Categories of the SCI, provides sufficient informational value to analyse the growth of science and technology fields, we decided to analyse the change within the categories of the classifications to facilitate a minimum of comparability between the different indicators. Furthermore, the extension of a classification by generating new categories is also an important indicator. Rampelmann (1999), Leydesdorff & Rafols (2008) and Li et al. (2007) go into more detail about the specifics of the division and allocation of categories and the benefits and shortcomings, such as late reclassification and empty categories.

To measure national specialisation, the comparative rates, a modified version of Balassas (Balassa, 1965) revealed comparative advantage (RCA), are calculated by:

$$RCA = 100 \cdot \tanh \ln \left[\frac{P_{ij} \big/ \sum_i P_{ij}}{\sum_j P_{ij} \big/ \sum_{ij} P_{ij}} \right] \tag{2.1}$$

where P_{ij} is the number of applications or publications of country i in field j, $\sum_i P_{ij}$ is the number of applications or publications of all countries in field j, $\sum_j P_{ij}$ is the number of applications or publications of country i in all fields and $\sum_{ij} P_{ij}$ the number of patent applications of all countries in all fields.

To calculate the ratio of a country's activities in a particular field, the number of patent applications in this field was related to the number of all patent applications of the country and interrelated with the same ratio of all countries (see Balassa (1965)). We further apply a logarithmic transformation to the ratio (modification introduced by Laursen (1998)). This logarithmic transformation has two effects. First, the measure is centered on 0 instead of 1, so that the value higher than 0 accounts for an over-specialisation in the measure, while the value below 0 accounts for an under-specialisation. Second, the logarithm integrates the notion of decreasing returns with extreme values of over- and under-specialisation. Furthermore, a hyperbolic tangent is applied to the measure. By applying this tangent, which has a steeply increasing functional form for low values and a limit that asymptotically approaches an absolute value of 1, we can limit the measure to the range between -1 and +1. The multiplication with a factor 100 is merely for illustrating purposes and can be omitted (modification introduced by Gehrke & Grupp (1994)).[1] The notion of over- and under-specialisation must not be confused with a value judgement of 'good' or 'bad' position. An over-specialisation can be the result of activities in a field that is declining in relevance measured against an overall reference.

To differentiate between an over-specialisation in a field of declining importance and an over-specialisation in a field of increasing importance, we include a measure that takes the notion of growth into account that again has to be measured against a frame of reference. Such a measure is found in the Sharpe Ratio (see Sharpe (1998)).

The described Sharpe Ratio is an indicator for the characterisation of the development momentum of a field, and it is calculated by:

$$SharpeRatio = \frac{W_F - W_G}{S_{WF}} \tag{2.2}$$

W_F is the growth of a specific field where $W = \frac{X_{t+1} - X_t}{X_t}$, W_G is the growth of all fields, S_{WF} the standard deviation of the growing field on an annual basis and X_t the number of patent applications at time t.

The Sharpe Ratio compares the growth rates of the output indicator in a field to a measure of centrality like the mean of the growth rates of all fields over a selected period of time. The selected indicators cover the different aspects of R&D, but also monitor diverse levels of abstraction and visualise different developments on a time

[1] A detailed overview of modifications of this formula can be found in Vollrath (1991); Laursen (2000); Reinert et al. (2008).

level. At the top level there are general long-term innovation cycles generated by technology push, underneath this level lie short-term developments with the focus on scientific topics. We illustrate this for scientific publications and patent applications by comparing the different levels.

The field and its standardisation activities are only of interest for further analysis if there is an above average increase in the output from the scientific community, in combination with positive growth rates in German activities, or if German activities in a specific field are under-represented (see the top right or bottom right quadrant of figure 2.4 in the next section).

2.2.1 Scientific publications

An accepted way of measuring the performance of established technologies is to analyse the output, i.e. scientific publications, of the science community. For the analyses of scientific publications, representative for the performance of the German basic research activities, we systematically surveyed the Science Citation Index (SCI) and the Social Science Citation Index (SSCI), two international databases for scientific journals with 172 and 52 subject categories published by Thomson Reuters. Figures 2.4 and 2.5 summarise some general findings on a higher aggregation level and in detail.

The analysis of the publication rates between 1999 and 2007 aggregated into 26 scientific fields and showed general concentrations on the areas: Biotechnology; medicine; geosciences; physics; nuclear technology; medical engineering as well as organic chemistry, i.e. high comparative literature rates and positive growth rates (Sharpe Ratios) (see figure 2.4).

The detailed consideration of the 172, respectively, 52 subject categories in the same period delivered the topics: agricultural economics and policy; anatomy and morphology; astronomy and astrophysics; chemistry, organic; biochemical research methods; dermatology and veneral diseases/dermatology; geochemistry and geophysics; microbiology; mineralogy; mycology; clinical neurology; neuroimaging; paleontology; psychiatry; radiology, nuclear medicine; rheumatology; transplantation as well as virology for the SCI and demography; environmental studies; mathematical psychology; public, environmental and occupational health for the SSCI (see figure 2.5).

The comparison of the results shorter time span, e.g. for 2005 and 2007 shows topics, which are observable over a longer period (e.g. neuroimaging, medical imaging and biochemical research methods) as well as a fraction of topics, which fluctuate over time. Table 2.2 shows the comparison of the results for 2007 and 2005.

Figure 2.4: Comparative literature rate (RLA) vs. sharpe ratios for German publications (1999-2007) in the SCI aggregated into 26 scientific fields.

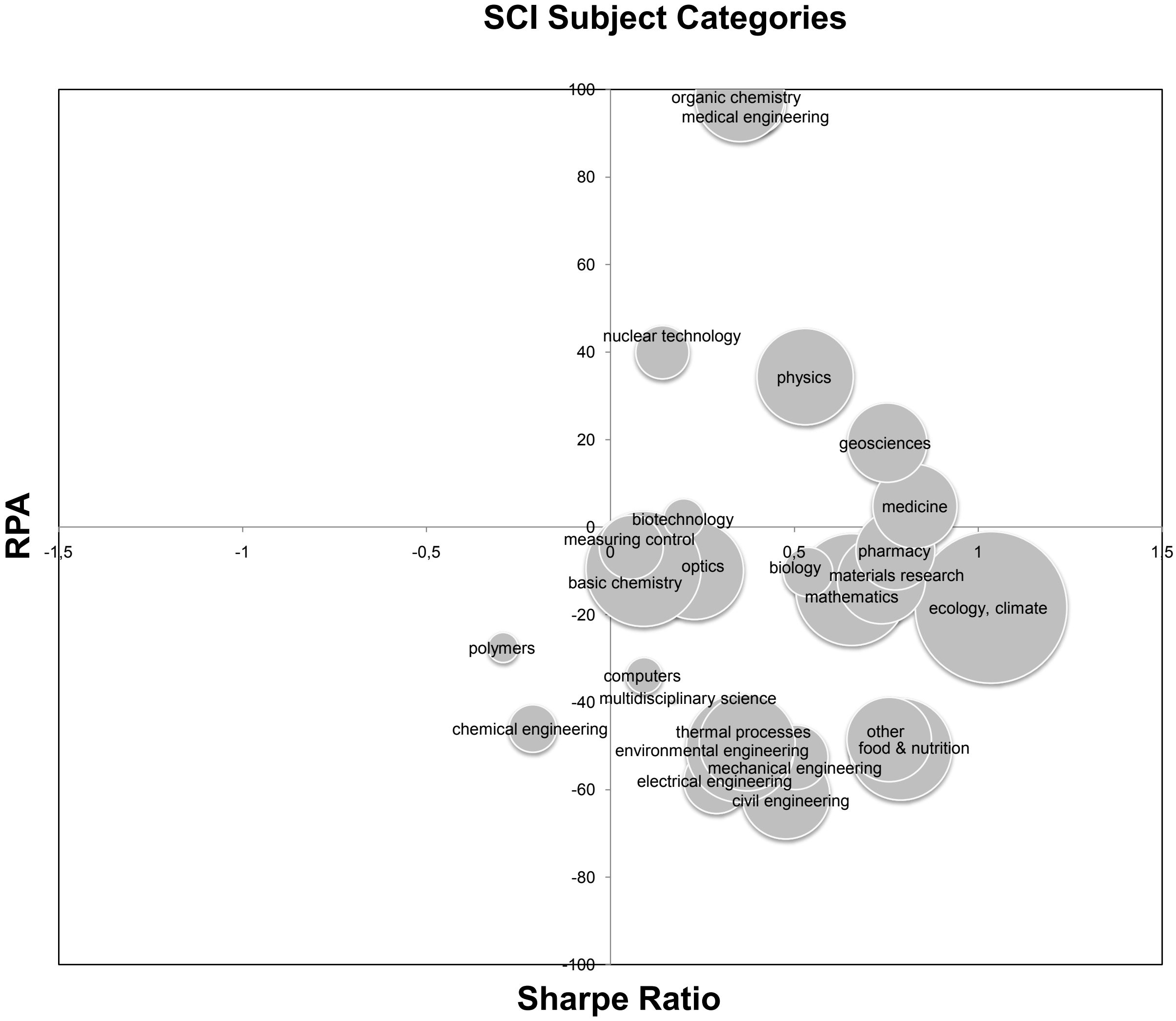
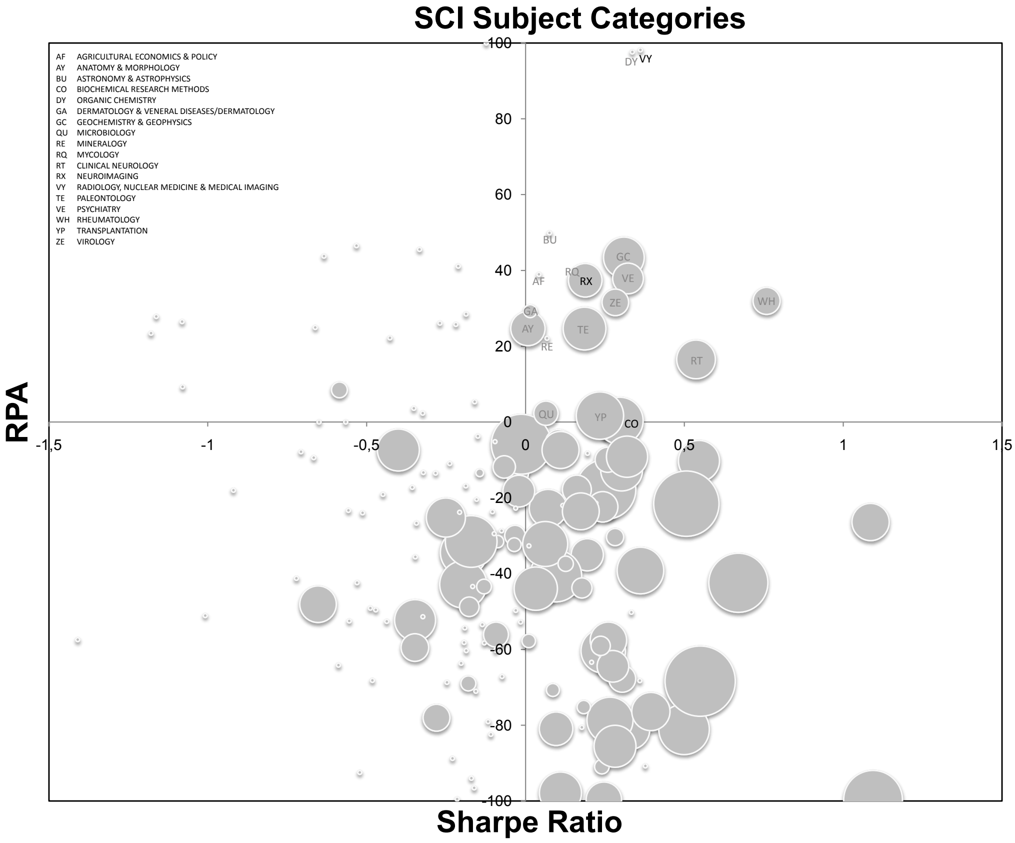


Figure 2.5: Comparative literature rate (RLA) vs. sharpe ratios for German publications (1999–2007) in the SCI and SSCI for 172 and 52 subject categories of the SCI and SSCI.



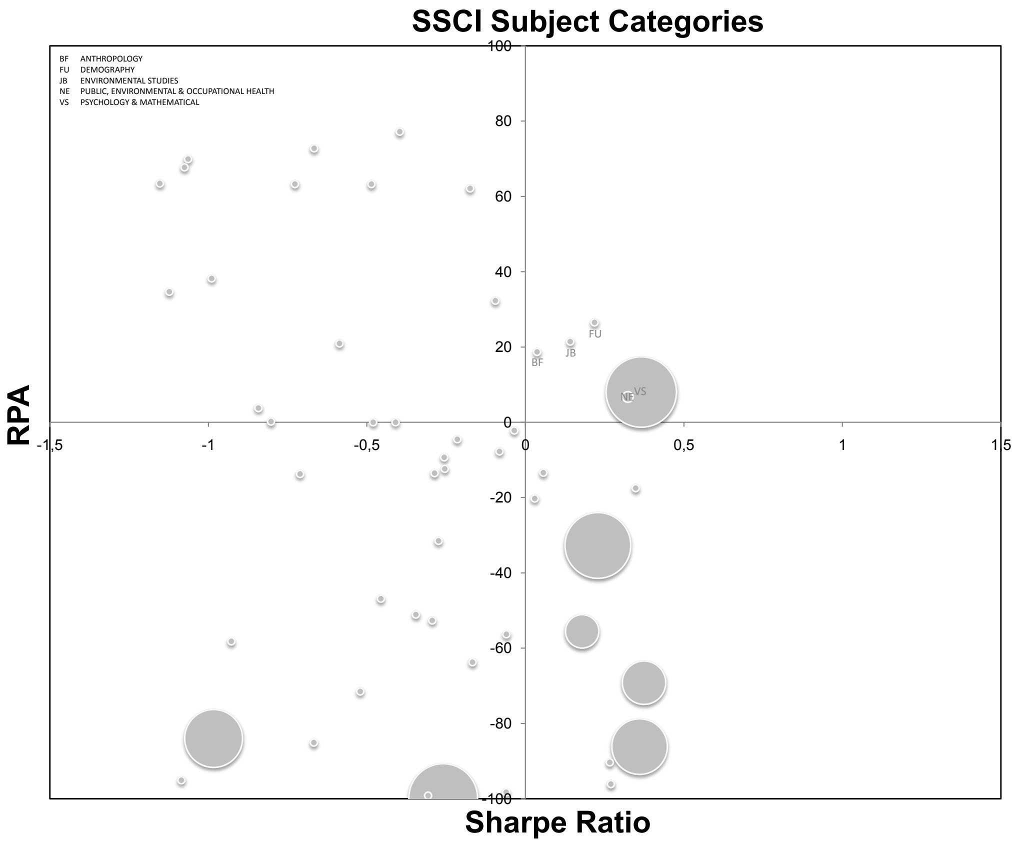


Table 2.2: Comparison of the results for topics with worldwide positive growth rates for 2007 and 2005.

Results for 2007	Results for 2005
• biochemical research methods • neuroimaging • radiology, nuclear medicine and medical imaging	• biochemical research methods • neuroimaging • radiology, nuclear medicine and medical imaging
• astronomy and astrophysics • organic chemistry • clinical neurology • geochemistry and geophysics • mycology • paleontology • psychiatry • rheumatology • virology	• nanoscience and nanotechnology • biomedical engineering • material science, biomaterials • computer science • information systems

2.2.2 Patent applications

For the analysis of patent applications, we evaluated data from the PATSTAT database, which includes patent applications at the European Patent Office (EPO). Some issues should be considered when investigating patent applications. Since there is generally a three-year time lag between patent application and patent grant, it is preferable to analyse patent applications rather than patent grants, due to the bias caused by rejection of patent applications. There is also an 18-months period before they are published. Therefore, we can only provide results for the time period from 2002 to 2005. Compared with scientific publication data of the SCI, which apply only to journals that are represented in the SCI, patent applications at the European patent office include all global regions and the statistics of patent data represent the activities of all applicants. The IPC is divided into sections, subsections, classes, etc.

The calculation of the Comparative Patent Rate and the Sharpe Ratios for patent applications at the EPO with at least one German inventor from 2002 to 2005 aggregated into 21 business sectors and shows general concentrations in the following areas: Electrical machinery, apparatus, energy; electronic components; telecommunications; audio-visual electronics; computers, office machinery; measurement, control; medical equipment; optics; basic chemicals, paints, soaps, petroleum products; special chemicals; polymers, rubber, man-made fibres; non-polymer materials; pharmaceuticals; energy machinery; general machinery; machine-tools; special machinery; motor vehicles; other transport equipment; metal products; textiles, wearing, leather, wood, paper, domestic appliances, furniture and food (see figure 2.6).

An examination of the IPC shows the following classes with a positive Comparative Patent Rate (RPA) and positive growth rates (Sharpe Ratios) for Germany and also worldwide: B44 decorative arts; F41 weapons; E06 doors, windows, etc.; F04 positive-displacement machines for liquids, etc.; C14 skins; hides, etc.; A24 tobacco, etc; B08 cleaning; G12 instrument details; B64 aircraft; aviation; aeronautics; E03 water supply, etc.; F28 heat exchange in general; H02 generation, conversion, or distribution of electric power; E05 locks; keys, etc.; B66 hoisting; lifting; hauling; B62 land vehicles for travelling otherwise than on rails; A47 furniture; domestic papers, etc.; F24 heating; ranges; ventilating; B60 vehicles in general; F03 machines or engines for liquids, etc.; F21 lighting; F25 refrigeration or cooling, etc.; F01 machines or engines in general, etc. and the following subclasses for 2005: A24C machines for making cigars or cigarettes; B23F making gear or toothed racks; B60D vehicle connections; B60J windows, windscreens, non-fixed roofs, doors, or similar devices for vehicles; B60S servicing, cleaning, repairing of vehicles; B61C locomotives, motor railcars; B61G couplings specially adapted for railway vehicles; B61H brakes or other retarding apparatus peculiar to rail vehicles; B63G offensive or defensive arrangements on vessels; mine-laying; mine-sweeping; submarines; aircraft carriers; C14C chemical treatment of hides, skins or leather; D21F paper-making machines; D21G calendars; accessories for paper-making machines; F16P safety devices; F23M constructional details of combustion chambers, etc. (see figure 2.7 and 2.8).

Table 2.3 compares the results for 2005 and 2004 showing the same pattern as described for scientific publications. The subclasses B60S, B61C, B61G, B60J and F16P can be found for both periods.[2]

[2] A listing of the IPC classification can be found on http://depatisnet.dpma.de/ipc/.

Figure 2.6: Comparative patent rate (RPA) vs. sharpe ratios for German patent applications (2002-2005) aggregated into 21 business sectors.

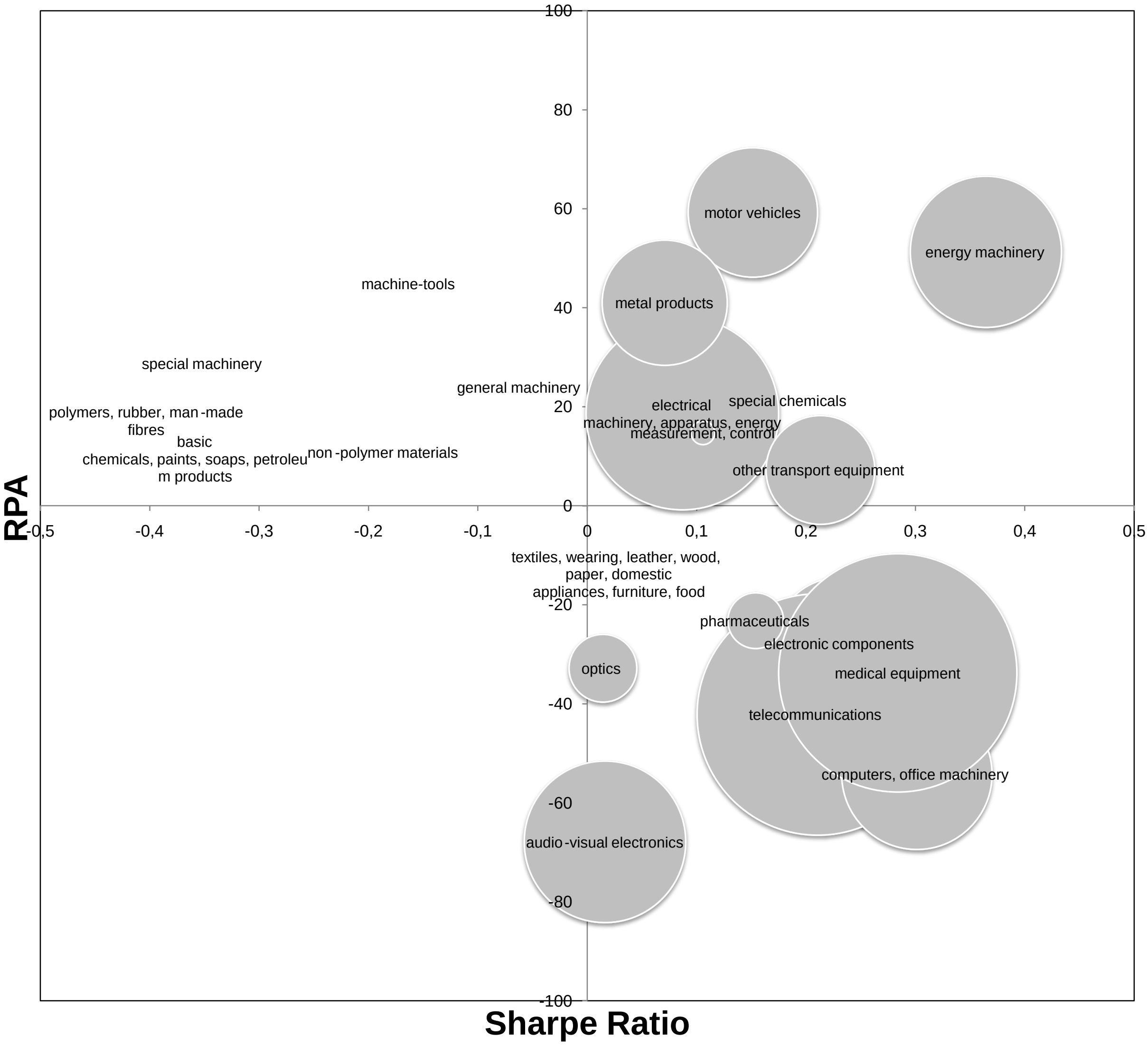


Figure 2.7: Comparative patent rate (RPA) vs. sharpe ratios for German patent applications (2002-2005) for 123 classes and 637 subclasses.

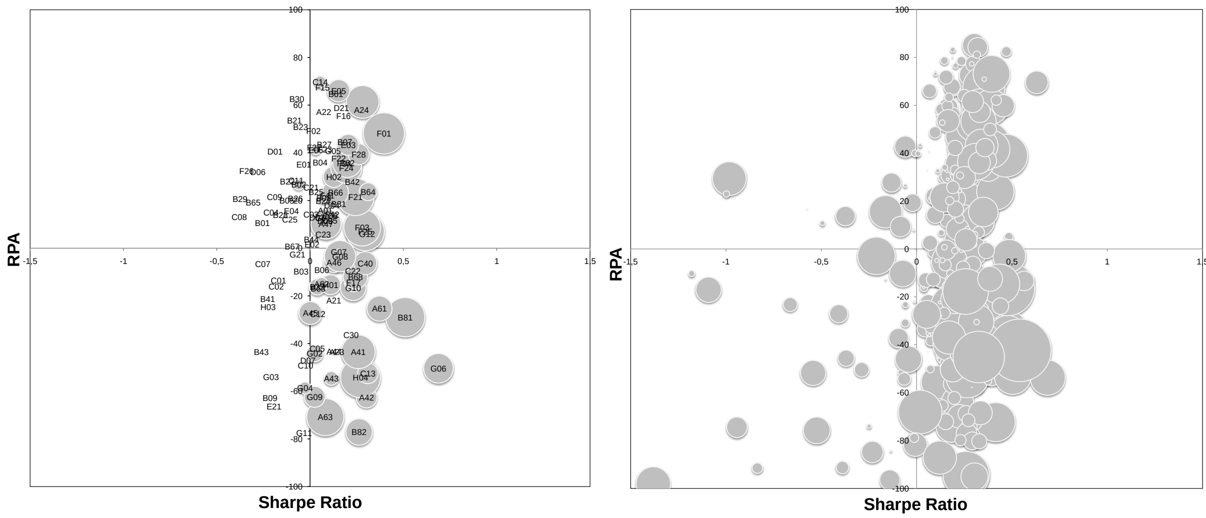


Figure 2.8: Comparative patent rate (RPA) vs. sharpe ratios for German patent applications (2002-2005) for subclasses in detail.

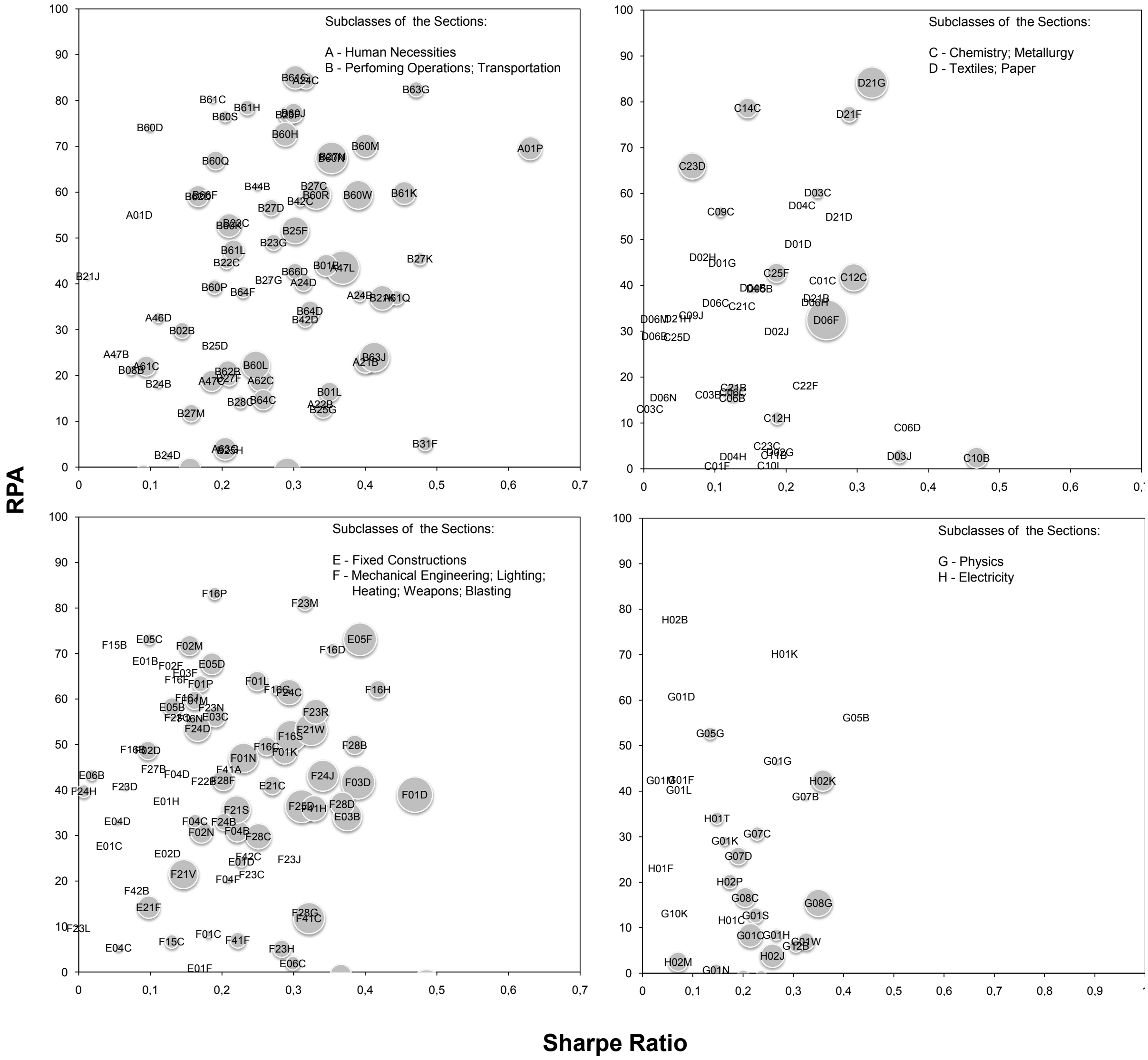


Table 2.3: Comparison of some results for 2005 and 2004.

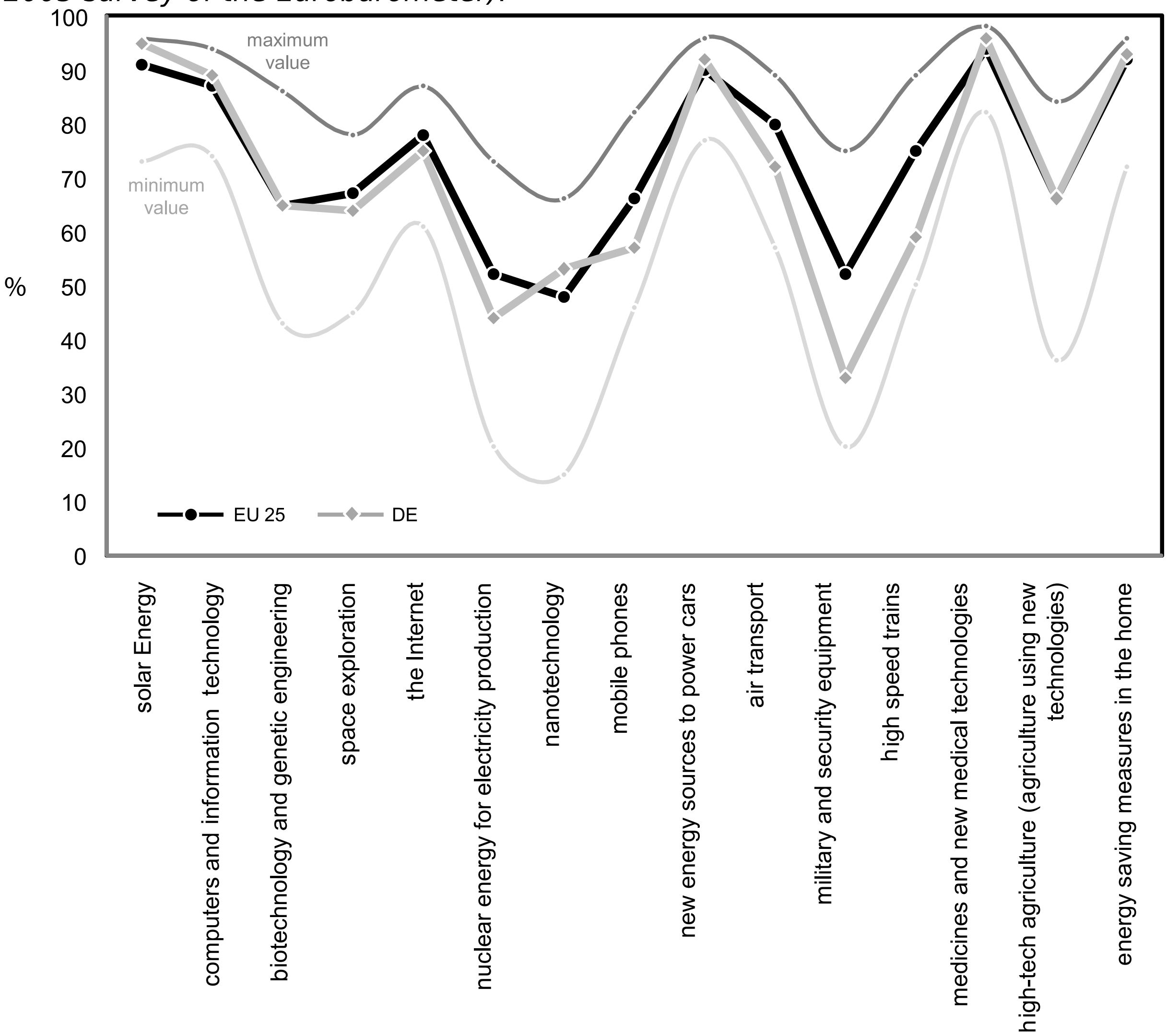
Results for 2005		Results for 2004	
• B60D	vehicle connections	• B60D	vehicle connections
• B60J	windows, windscreens, non-fixed roofs, doors, or similar devices for vehicles	• B60J	windows, windscreens, non-fixed roofs, doors, or similar devices for vehicles
• B60S	servicing, cleaning, repairing of vehicles	• B60S	servicing, cleaning, repairing of vehicles
• B61C	locomotives, motor railcars	• B61C	locomotives, motor railcars
• B61G	couplings specially adapted for railway vehicles	• B61G	couplings specially adapted for railway vehicles
• F16P	safety devices	• F16P	safety devices
• A24C	machines for making cigars or cigarettes	• A61C	dentistry
• B23F	making gear or toothed racks	• A61Q	use of cosmetics or similar toilet preparations
• B61H	brakes or other retarding apparatus peculiar to rail vehicles	• C10B	destructive distillation of carbonaceous materials for production of gas, coke, tar, or similar materials
• B63G	offensive or defensive arrangements on vessels; mine-laying; mine-sweeping; submarines; aircraft carriers	• C10K	purifying or modifying the chemical composition of combustible gases containing carbon monoxide
• C14C	chemical treatment of hides, skins or leather	• D01H	spinning or twisting
• D21F	paper-making machines	• D06P	dyeing or printing textiles
• D21G	calendars; accessories for paper-making machines	• E03F	sewers; cesspools
• F23M	constructional details of combustion chambers etc.	• F03D	wind motors
		• F28B	steam or vapor condensers etc.

2.2.3 Technology acceptance

Since standardisation has to be responsive to the changes and challenges of the market, customer-demand-driven indicators were also analysed. Here, the acceptance of innovative technologies is an important issue. Some of these innovative technologies, for example environmental technologies, may have positive effects on social welfare. However, acceptance levels for others may curtail impulses for a market launch. Innovative technologies, which are fraught with risk, are considered with more scepticism, e.g. some knowledge properties in the field of nanotechnology. This scepticism is confirmed by the 2005 survey of the Eurobarometer (see figure 2.9). Here the citizens in 25 countries of European Union were questioned to evaluate the expected impact of new technologies. The minimum and maximum values of the country estimations show the variance of the countries. The results show that Germany has a positive attitude towards new technologies. In particular, solar energy, new energy resources and medical technologies as well as nanotechnology were assessed with high expected impact.

In comparison to the average European value the German ratings for nuclear energy, mobile phones, speed trains as well as military and security equipment were much lower. This could indicate to prejudice in the population. Standards could contribute to removing market barriers and allaying consumer scepticism.

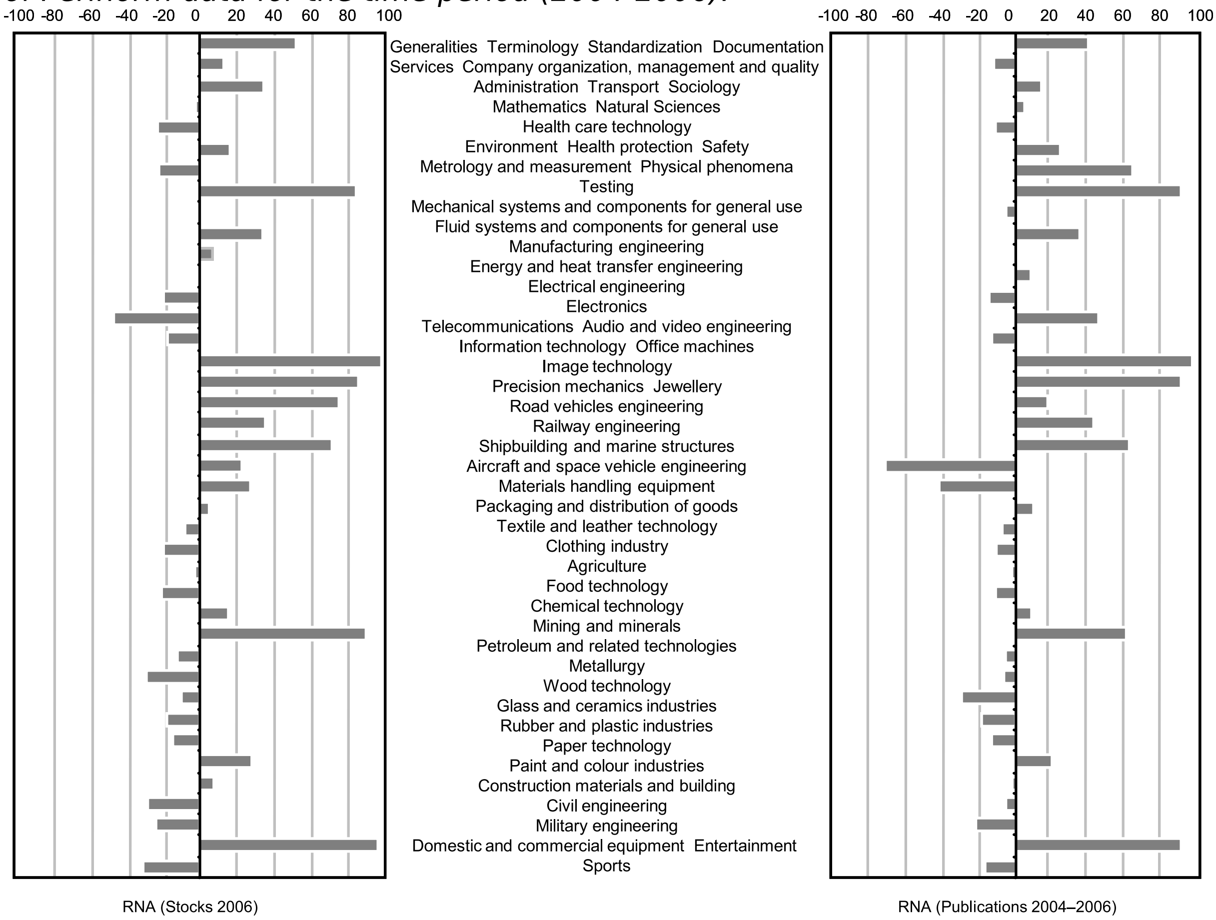
Figure 2.9: Expected impact of new technologies on citizens' life (data from the 2005 survey of the Eurobarometer).



2.2.4 Standard documents

A variety of empirical surveys (e.g. Compañó & Hullmann (2002); Heinze (2004)) and our indicator results show the important role of Germany in both research publications and patent applications. However, these studies also prove a lack of progress in standardisation activities in Germany. The results for the German comparative rate for standards publications in the Perinorm database of the DIN[3] show an overview of the over-represented classes (see figure 2.10). Comparing the results for the previously described indicators with the results of the standard publications can make the areas in which new standards are necessary visible.

Figure 2.10: German comparative rates for standard publications and their stocks of Perinorm data for the time period (2004-2006).



Another way of measuring the performance of emerging technologies is to track the establishment of new working groups within existing technical committees or the foundation of new technical committees. With respect to our example, Blind & Gauch (2009) give an overview of national, European and international standardisation activities in the field of nanotechnology from 2003 to 2006. In the annex, currently published ISO standardisation documents and standards under development related to the technical committee on nanotechnology are summarised. The USA, China and the UK first became active in this committee in 2003, and the UK took the leading position in proposing and finally managing the European technical committee on nanotechnology and also achieved the leading position in the international standard activities of ISO standard activities of ISO (see tables 2.5 and 2.6 in the annex). Blind & Gauch (2009) argue that the market success of nanotechnol-

[3] DIN German Institute for standardisation e.V.

ogy applications largely depends on the development of corresponding standards, which not only clarify terminology, measurement and testing methods, but also regulate safety and health aspects and specify interfaces.

2.3 Delphi surveys

On the basis of the results of the set of indicators, detailed two-round Delphi surveys for areas of technology characterised by strong research activities of German scientists in public research organisations, such as universities, and in companies actively involved in research were carried out. The demand for specific standardisation types that are required for emerging technologies was analysed. Several areas have been evaluated since 2006, and nanotechnology was chosen for the first pilot study. Further topics of interest were explored as a result of the refined indicator approach. Various indicators allowed us to identify potential experts and future stakeholders related to these specific emerging fields, such as scientists, inventors, research facilities and innovative companies. These were mainly scientific publications in journals, European patent and brand applications and different databases, networks and internet facilities and industry active in publishing scientific papers and applying for patents. Representatives of relevant establishments, such as environmental associations, consumer organisations, professional associations, unions and regulation bodies, not yet active in standardisation were contacted.

This section describes the results of the nanotechnology survey. The field of nanotechnology was chosen as a pilot survey because of Germany's strong position in R&D[4], its substantial national and European public funding initiatives, its first standardisation activities on terminology, measurement and testing, and the demand for regulation on health and environmental issues. Almost 1500 experts in the field of nanotechnology were contacted. In the first survey round, nearly 100 experts (exactly 95) responded to the online Delphi survey. Approximately 50% (49 experts) answered in the second round. According to Blind et al. (2001), this is a sufficient number of expert responses, compared with other large-scale Delphi exercises conducted in Germany, to provide a general assessment about the future needs for standards in the field of nanotechnology.

The experts were asked to assess topics identified by an in-depth literature survey according to the recommended timing of standardisation, their importance along various dimensions, the type of standard and level of enactment. As a result, relevant and urgent standardisation topics initiating anticipated standardisation processes could have been prioritised. The topics include the following main categories: Nanoparticles; measuring and testing methods; effects of enhanced

[4] Here the results of the indicator analysis showed nanotechnology as an emerging field in scientific publications.

chemical reactivity on health and interaction as well as various areas of application (e.g. foodstuffs; biotechnology, medical science and cosmetics; ICT; material sciences; automotive industry plus agriculture). The experts found that standards in the area of nanotechnology are necessary to address environmental and safety concerns, whereas they are not considered so important for technical and economic development.

Standards in the following fields are of highest priority from the perspective of the experts:

- Material composition,
- Surface analysis,
- Multiple coordination probing and positioning, position indicating systems,
- Size and geometric specifications for sample probing, and
- Destruction-free measuring.

Not only measurement and testing standards, but also quality standards are needed, particularly, in the field of nanotechnology. Furthermore, in 2006 there was a significant need for terminology standards. However, compatibility of final product standards was of low priority from the perspective of the experts. Table 2.4 and figure 2.11 summarise this assessment and give an overview of the recommended timing of standardisation of the conducted Delphi survey. Table 2.4 shows the evaluation of the required types of standards for the different standardisation issues. The results and especially the dominance of measurement and testing standards show the novelty of the field. Figure 2.11 outlines all evaluated standardisation issues and their recommended standardisation timing.

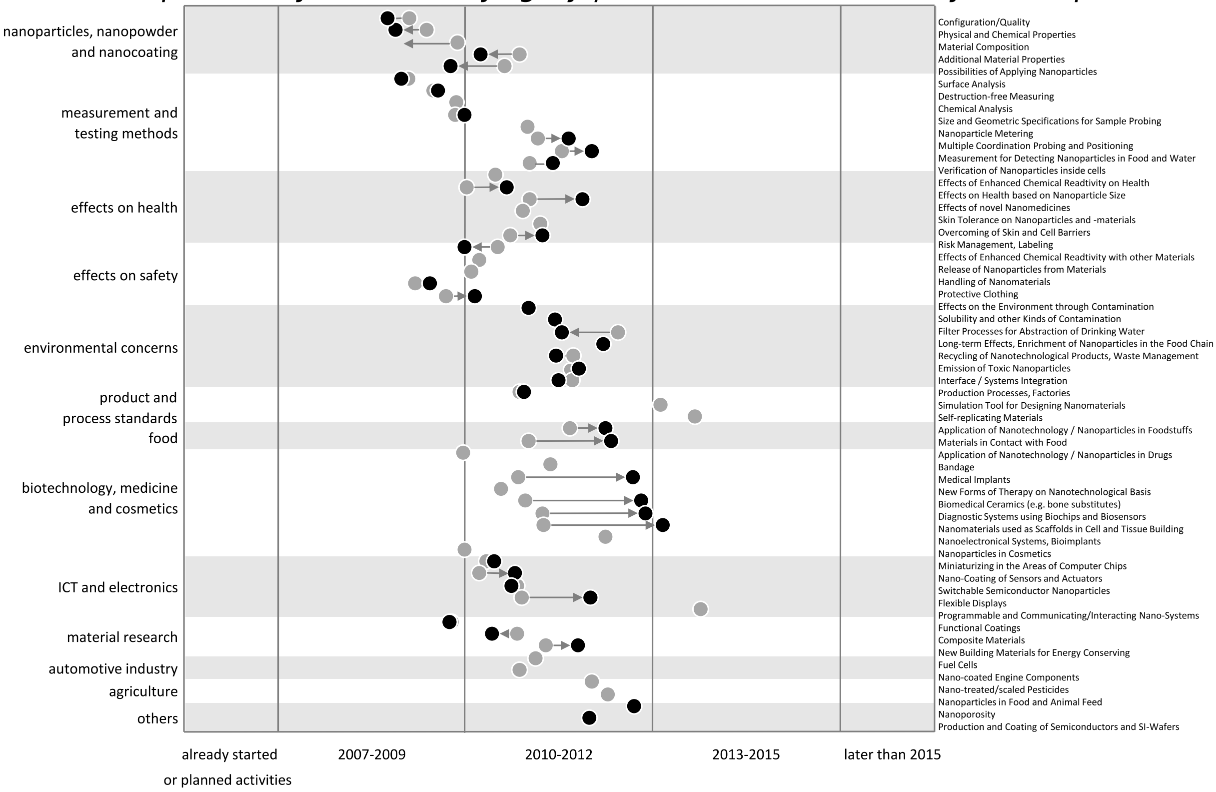
The results of the two Delphi rounds show significant differences in the evaluation of the timing of some standardisation issues. Based on the assessments a prioritised list of future standardisation activities could be created. The detailed results especially of the response distributions could give more details about discussion and coordination requirements within the communities.

Besides providing information about future innovative standardisation fields, the surveys emphasise the importance of standardisation for scientists and companies, in general, and encourage their active involvement in standardisation processes. The results provide new ideas for future standardisation activities in collaboration with officials from standardisation bodies accompanying technical committees, and may attract scientists, research facilities and innovative companies to become involved in standardisation.

Table 2.4: Required types of standards.

	terminology standards	measurement and testing standards	quality and safety standards	compatibility standards	product and service standards
Configuration/Quality	•	••	•		
Physical and Chemical Properties	•	••	•		
Material Composition	•	•	•		
Additional Material Properties		•	•		
Possibilities of Applying Nanoparticles		•	•		•
Surface Analysis	•	••	•		
Destruction-free Measuring	•	•	•		
Chemical Analysis		•	•		
Size and Geometric Specifications for Sample Probing	•	•			
Nanoparticle Metering	•	•	•		
Multiple Coordination Probing and Positioning, Position Indicating Systems		•			
Measurement for Detecting Nanoparticles in Food and Water		•	•		
Verification of Nanoparticles inside cells		•	•		
Effects on Health			•		
Toxicity of Nanoparticles		•	•		
Effects on Health based on Nanoparticle Size		•	•		
Effects of novel Nanomedicines			•		
Skin Tolerance on Nanoparticles and -materials			•		
Overcoming of Skin and Cell Barriers/Boundaries by Nanoparticles			•		
Risk Management, Estimation of Risk and Danger Potential, Labeling			•		
Effects of Enhanced Chemical Readtivity with other Materials/Substances		•	•		
Release of Nanoparticles from Materials		•	•		
Handling of Nanomaterials		•	•		
Protective Clothing			•		
Interface/Systems Integration		•			
Application of Nanotechnology/Nanoparticles in Foodstuffs			•		
Materials in Contact with Food (e.g. Packaging Materials))			•		
Miniaturising in the Areas of Computer Chips, Computer Memory and & Optoelectronics	•	•			
Nano-Coating of Sensors and Actuators		•			
Functional Coatings (Soil-resisting, Nano Induration)		•	•		

Figure 2.11: Overview of the recommended timing of standardisation of the conducted Delphi survey (first survey: grey points and second survey: black points).



2.4 Discussion and study limitations

Our foresight activities to identify future fields of standardisation lead us to the following insights and recommendations. There is a need to improve the methodology of standards foresights focusing on future strategies and standardisation activities and the special technology indicators to detect future fields of standardisation have yet not been fully developed. Data reflecting the state of the art in science and technology as well as micro-data indicating the views of actors on potentials for standardisation provide further information about standardisation-relevant contents. Moreover, micro-data on topics such as health, environmental and safety aspects can uncover issues that may be of concern for the general public, which might also help to identify barriers for emerging fields of standardisation. We have used bibliometric and patent data to identify individual stakeholders, companies and researchers, which could be involved in future standardisation processes.

Our methodological approach is limited in several ways: A Delphi survey is a rather time-consuming approach in terms of clustering and grouping individual topics. It also requires an accurate preliminary investigation and the involvement of a multitude of experts. In new and emerging fields, these experts might not be readily available to support technical knowledge that can be necessary to cluster topics into larger agglomerations. This problem becomes more pronounced with the level of detail in the respondents' answers to open questions. In cases where the level of detail is very high, connections and similarities between individual respondents might only be apparent to technical experts.

In some cases, it would be helpful to use further methodologies and tools for computer-assisted methods, like text mining for the analysis of word frequencies and co-occurrences for the evaluation of content proximity (see Ding et al. (2001); Small (2006); Calero et al. (2006)) or the analysis of journal citations for the identification of technology trajectories (see Verspagen (2005); Fontana et al. (2008)). Still, such methods might be preferable if the task is to extrapolate the general development of technologies, but it is not sufficient to identify those topics that might require future standardisation. Since the assessment of the necessity to standardise certain aspects of a technology is subjective in nature, the opinions of experts are necessary to identify relevant topics.

On the basis of the existing experiences with Delphi surveys, it can be concluded that this methodology allows the identification of very specific future standardisation issues. However, the reliability and validity of the results depend crucially on the identification of the adequate sample of stakeholders. The responses of Delphi surveys are only useful if all relevant stakeholder groups are adequately addressed and strategic responses can be corrected. Otherwise, this approach produces rather biased assessments. Consequently, the combination of indicator-based approaches, which at least allow the identification of stakeholders in science and technology working in both research institutes and private companies, is an option to improve the reliability and the validity of survey results. However, it is much more difficult to select stakeholders from the user and even the consumer side, and to integrate them into the Delphi approach. The same is true for representatives of public organisations and regulatory bodies, which also cannot be identified by the use of science and technology indicators.

In general, the application of Delphi studies for standardisation foresight faces the similar strengths and weaknesses as using this approach to identify future trends in science and technology. In addition, the range of stakeholders and experts to be integrated in a Delphi survey is wider and more complex, since members of public organisations, e.g. regulatory bodies, also have to be addressed in addition to experts in science and technology, possible users and consumers. This more complex community of experts also makes it more difficult to design a Delphi questionnaire. Furthermore, the time frame of Delphi studies focusing on standardisation issues should be much shorter covering only the next 10 years, since the need to develop new standards and to adopt existing standards can only be assessed if specific perspectives of commercial applications of new sciences and technologies already exist. However, basic terminology issues should be addressed at the very beginning of a newly emerging field of science and technology. This was missed in the case of nanotechnology and it provides a crucial argument for standardisation bodies to be involved in systematic foresight activities.

To address the weaknesses of both a purely indicator-based view and a purely subjectively driven approach, a method, which integrates an objective, quantitative and predictive analysis based on indicators and a subjective, qualitative and normative analysis based on expert opinions, can help to identify relevant fields for future standardisation activities. The method proposed in this paper is only one potential way of conducting such an analysis. A sequence that, in the first step, uses quantitative and indicator-based methods to narrow down potential topics keeping in mind the above-mentioned perspective of competitive advantage in a certain technology for a given country was deliberately chosen. In the second step, an attempt to identify potential topics based on the subjective assessments of relevant actors was made. At the moment, the methods used by standardisation bodies only reflect the latter approach by deploying expert workshops where the initial impulse both in terms of topics and relevant experts is not necessarily based on external knowledge. This can result in missing possible new developments, at least to some extent. From this perspective, an indicator-based approach might also help to identify relevant topics and actors. Expert workshops can follow in the second step, instead of conducting a Delphi analysis.

This assessment of our approach shows that a simple transfer from applying the methodologies to identify emerging science and technology fields into standardisation foresight is not sufficient. Further significant adjustments and developments have to be made to achieve an adequate methodological base, which allows standardisation foresight analyses that can produce valid and reliable results. Such analyses cannot only be done by standardisation bodies, because they generally lack experience in foresight activities. A shift towards methods of standardisation foresight also requires stakeholders to become proactively involved.

Acknowledgements

This work was funded by the Federal Ministry of Economics and Technology in the context of the INS project (see www.ins.din.de). We also acknowledge the DIN German Institute for Standardisation e.V. for their valuable collaboration.

Table 2.5: Published ISO Standards related to TC 229 – Nanotechnoloies (www.iso.org, September 2009).

ISO/TS 27687: 2008	Nanotechnologies – Terminology and definitions for nano-objects – Nanoparticle, nanofibre and nanoplate (German version CEN ISO/TS 27687: 2008)
ISO/TR 12885: 2008	Nanotechnologies – Health and safety practices in occupational settings relevant to nanotechnologies
ISO/DIS 10801: 2009	Nanotechnologies – Generation of metal nanoparticles for inhalation toxicity testing using the evaporation/condensation method (German version prEN ISO 10801: 2009)
ISO/DIS 10808: 2009	Nanotechnologies – Characterization of nanoparticles in inhalation exposure chambers for inhalation toxicity testing (German version prEN ISO 10808: 2009)

CD = Committee Draft　NP = New Work Item Proposal　TR = Technical Report
DIS = Draft International Standard　TS = Technical Specification　WD = Working Draft

ISO committees in liaison:TC 24/SC 4, TC 48, TC 61, TC 142, TC 146/SC 2, TC 150, TC 184/SC 4, TC 194, TC 201, TC 202, TC 206, TC 207, TC 207/SC 1, TC 209, TC 213, TC 215, TC 246

Table 2.6: Standards under development related to TC 229 – Nanotechnologies (www.iso.org, September 2009).

ISO/AWI TS 10812	Nanotechnologies – Use of Raman spectroscopy in the characterization of single-walled carbon nanotubes (SWCNTs)
ISO/CD TS 11251	Use of evolved gas analysis-gas chromatograph mass spectrometry (EGA-GCMS) in the characterization of single-walled carbon nanotubes (SWCNTs)
SO/AWI TS 11308	Use of thermo gravimetric analysis (TGA) in the purity evaluation of single-walled carbon nanotubes (SWCNT)
ISO/AWI TR 11808	Guidance on nanoparticle measurement methods and their limitations
ISO/AWI TR 11811	Guidance on methods for nanotribology measurements
ISO/AWI TS 11931-1/-2	Nano-calcium carbonate Part 1: Characteristics and measurement methods Part 2: Specifications in selected application areas
ISO/AWI TS 11937-1/-2	Nano-titanium dioxide Part 1: Characteristics and measurement methods Part 2: Specifications in selected application areas
ISO/AWI TS 12901-1/-2	Part 1: Guidance on safe handling and disposal of manufactured nanomaterials Part 2: Guidelines for occupational risk management applied to engineered nanomaterials based on a "control banding approach"
ISO/AWI TR 13014	Guidance on physico-chemical characterization of engineered nanoscale materials for toxicologic assessment
ISO/AWI TR 13121	Nanomaterial Risk Evaluation Framework
ISO/DIS 29701	Endotoxin test on nanomaterial samples for in vitro systems – Limulus amebocyte lysate (LAL) test
ISO/CD TR 80004-1 to -9	Terminology and definitions – Framework Part 2: Core terms Part 4: Carbon nano-objects Part 5: Nanostructured materials Part 6: Bio/nano interface Part 7: Nanoscale measurement and instrumentation Part 8: Medical, health and personal care applications Part 9: Nanomanufacturing processes
ISO/CD 12025	Nanomaterials – General framework for determining nanoparticle content in nanomaterials by generation of aerosols
ISO/AWI TS 12805	Guidance on specifying nanomaterials
ISO/NP TR 13329	Preparation of Material Safety Data Sheet (MSDS)
ISO/NP TS 13278	Carbon nanotubes – Determination of metal impurities in carbon nanotubes (CNTs) using inductively coupled plasma-mass spectroscopy (ICP-MS)
ISO/WD TS 10797	Nanotubes – Use of transmission electron microscopy (TEM) in walled carbon nanotubes (SWCNTs)
ISO/WD TS 10798	Scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDXA) in the charaterization of single walled carbon nanotubes (SWCNTs)
ISO/CD TS 10867	Use of NIR-Photoluminescence (NIR-PL) Spectroscopy in the characterization of single-walled carbon nanotubes (SWCNTs)
ISO/CD TS 10868	Use of UV-Vis-NIR absorption spectroscopy in the characterization of single-walled carbon nanotubes (SWCNTs)
ISO/CD TR 10929	Measurement methods for the characterization of multi-walled carbon nanotubes (MWCNTs)
ISO/NP TS 13126	Artificial gratings used in nanotechnology – Description and measurement of dimensional quality parameters

CD = Committee Draft   NP = New Work Item Proposal   TR = Technical Report
DIS = Draft International Standard   TS = Technical Specification   WD = Working Draft

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3 Identification of Future Fields of Standardisation – An Explorative Application of the Delphi Methodology

Abstract

This paper investigates the application of the Delphi methodology for the identification of future fields of standardisation complemented by a methodological extension by using various science and technology indicators. By the term standardisation, we broadly mean the process of developing and implementing technical standards within a standardisation body. Underlining the explorative nature of this paper, the process of identifying future fields of standardisation is described. To provide a systematic forecasting view on complex science and technology fields, a combination of quantitative indicator-based analyses and qualitative in-depth Delphi surveys is chosen. Firstly, statistical analyses of suitable indicators are used to identify dynamic developments in such fields. Secondly, to identify detailed challenges for future standardisation, qualitative Delphi surveys are conducted. To collect and evaluate relevant issues the respective expert communities were included. They were identified by using information derived from the science and technology databases used. The paper is concluded with the assessment of the chosen approach and gives practical insights for its feasibility based on a review of the existing literature on the Delphi methodology. In addition, an outlook for further improvements and other possible fields of application is given.

Keywords

Standardisation foresight, Delphi, science and technology indicators

Contents

3.1 Introduction

Foresight activities are considered to be multi-stage processes. They are always marked by a variety of objectives. Nevertheless, there is one primary purpose for the implementation of foresight in general: The identification of future areas of science and technology in which an organisation, e.g. a country, a company or a research organisation, can achieve an international forerunner position. As Martin (1995) puts it:

> The ultimate objective of foresight is to ensure that areas of science and technology that are likely to yield future socio-economic benefits are identified promptly.

The identification of such future fields can only be achieved by examining the science and technology base, the institutional constitution and the economic strength of a country or of an organisation. This should be put into the context of general technological developments. In other words, a country's or a company's ability to produce and commercialise the flow of new technologies over a longer period of time (Furman et al., 2002) is essential for their economic development. The potential to innovate, as well as other important determinants of the innovation process are summarised in the national innovation system (see for example Arnold et al. (2001)). It also includes the capabilities or the economic competence of the actors of the system to generate, diffuse and commercialise technologies (Carlsson et al., 2002). Here standardisation can enhance these capabilities.

By the term standardisation, we broadly mean the process of developing and implementing technical standards. By including all interested stakeholders, the standardisation process aims at avoiding technical application obstacles by unifying and standardising. More precisely, a published de-jure standard specifies fixed rules, guidelines or characteristics for tasks and their results. It is a universally accepted and generally applicable rule. Standards are created by a consensual process and are approved by a recognised institution, such as a national standard body (NSB).[1] However, they have the form of recommendations, unless their compliance is obligatory under national or international laws or regulations. By promoting the diffusion of technological knowledge by creating and using de-jure standards and technical guidelines, standards are considered to be necessary for the economic development of a technology.

Despite its economic importance, there is a lack of references on scientific findings in the day-to-day business of standardisation committees. This is the result of frictions between current scientific research and the roadmap of future standardisation processes. This problem in mind, a supplementary indicator-Delphi approach

[1] See also the definition of the term de-jure standard in EN 45020.

for conducting systematic foresight studies for the identification of future fields of standardisation was developed. This approach is also applicable to other foresight application areas. The approach supplements the classical Delphi approach with statistical analyses of indicators, which provides a sound overview of complex science and technology fields. The indicator approach is used to identify future dynamic fields in science and technology as well as possible panel experts for subsequent Delphi surveys. Based on the results of this first analysis, in-depth online Delphi surveys with consecutive rounds will be carried out, both qualitative and quantitative. Using the implicit knowledge of participants, the methodology reveals conflicting as well as consensus areas (Blind, 2008) for these fields.

This article focuses on three different objectives. (1) Investigates a possible extension of the Delphi technique using a combination of quantitative indicator-based analyses and qualitative in-depth Delphi surveys. To introduce the method, the set of indicators and some possibilities for the statistical and bibliometric analysis are specified. In addition, specific methodological characteristics are elaborated. (2) By applying this approach to standardisation foresight, a novel practical application area for the Delphi methodology is introduced. This paper especially focuses on the exploratory study of the application area. In particular, the characteristics of the stakeholders of standardisation processes are described. (3) Finally, the applicability of the method will be evaluated. For this purpose, it will be discussed whether the indicator approach is a useful addition, especially for the identification of key experts for Delphi surveys and weather it can be used in other application areas.

The remainder of this article is structured in the following way: Section 3.2 gives practical preliminary considerations for standardisation foresight. Section 3.3 provides theoretical background on science and technology indicators, the Delphi technique, and the role of standardisation in the R&D process. Section 3.4 gives a more general description of the method. It is followed by a comparative analysis of conducted case studies in section 3.5. In addition, modifications made to the approach, addressing some practical issues, are described. The paper concludes in section 3.6 with some methodical considerations as well as practical insights for its feasibility. Recommendations and limitations of the approach, as well as its use in other application areas are discussed.

3.2 Practical preliminary considerations

To choose an appropriate foresight approach for identifying topics of standardisation, it is necessary to consider the general characteristics of the standardisation processes. As in many coordination processes, adequate stakeholder participation is essential to standardisation. Nevertheless some standardisation processes are characterised by an unbalanced stakeholder representation (de Vries et al., 2003).

Even though the relevance of standards in basic research is notably high, research institutions are underrepresented in many standardisation committees. Negative impacts on quality and application of resulting standards are most likely (de Vries et al., 2003).

Standardisation processes are multi-stage coordination processes resulting in a consensual standard, established in collaboration with the standardisation bodies. Many heterogeneous stakeholders are involved, who act on their individual interests. Many of these characteristics hold true for Delphi approaches as well, or can be reproduced by them. In addition, Delphi surveys, with their consecutive rounds and intermediate feedback resemble the standardisation coordination processes, but lack the interactive parts of committee group discussions. Furthermore, the primary purpose of the Delphi methodology is to obtain the most reliable consensus of opinion of a group of experts (Gupta & Clarke, 1996; Dalkey & Helmer, 1962). Table 3.1 summarises these similarities. Considering all these points, the Delphi technique seems to be an adequate method for determining future standardisation issues.

Table 3.1: Similarities between standardisation processes and Delphi surveys.

	Delphi Survey	Standardisation Process
Stakeholder	• adaptable for a heterogeneous circle of respondents	• involvement of heterogeneous stakeholders
Process	• multi-stage assessment and coordination process	• long-lasting multi-stage coordination process
Results	• setting priorities • aiming for consensual results • dependent on the involved experts	• setting priorities • decision-making by consensus • dependent on the involved stakeholders

In both processes the selection of panellists or stakeholders is a matter of high importance and presents a difficult task. For Delphi approaches, Häder (2000) makes the recommendation that the selection process should be oriented towards the function and objectives of the survey.

The objective targets of standardisation foresight are oriented towards two typologies (see Martin (1995); Häder (2000)). The typology by Martin (1995) classifies foresight methods along several key features, characteristics and intermediate functions. It distinguishes between: (a) direction setting, i.e. establishing broad guidelines for policy or regulation; (b) determining priorities; (c) anticipatory intelligence, i.e. providing background information and an early warning of recent developments; (d) consensus generation; (e) advocacy for a new research initiative or defending an existing program; and (f) communication and education within the research community. The typology by Häder (2000) outlines main objectives of Delphi surveys: (a) idea generation, which, in contrast to the classical Delphi approach, evaluates qualitative responses; (b) exact prediction of an uncertain fact; (c) evaluation of the opinion of a group of experts about a diffuse fact; and (d) reaching a consensus among the participants.

The primary purpose of this study is to provide general directions for future activities, i.e. the attempt is made to identify major growing fields of science and technology. Motivated by the underrepresentation of the research community in standardisation processes, it is also the intention to increase the sensitivity of researchers and research organisations with respect to the importance of standardisation and standards. This information or signalling functions of this approach plays an important role in the recruitment of new stakeholders for standardisation processes. The surveys of the Delphi methodology also serve a communication function, not only to communicate the consensus among the participants but also to raise awareness. Foresight experts consider the consultative process with involvement of the corresponding community, equally or even more important than the foresight outcome (see Blind (2008)). The aim is also to achieve the integration of R&D and standardisation activities. Here, quantitative Delphi survey rounds cover new impulses and recent developments in science. In addition, the recommended timing, i.e. the starting of standardisation activities, should be evaluated. As a result, relevant and urgent standardisation topics can be prioritised.

3.3 Conceptual background

In this section a theoretical background on the applied method combination is given. To gain deeper insight the three most important aspects are regarded separately. This includes theory on science and technology indicators, research on the Delphi technique, as well as the role of standards and their economic background.

3.3.1 Science and technology indicators

The discipline of quantitative science and technology research focuses on the analysis of the development and application of innovation indicators. Such indicators are derived from data on scientific and practical publications or patents applications (Moed et al., 2004). Therefore, different methods provide analyses for technological and innovation development at different levels of the technological development (e.g. analyses of individuals, research groups, researcher networks, institutions, regional, national and even supra-national levels) (Moed et al., 2004). Science and technology (S&T) indicators can be used to estimate the innovation potential, technological capabilities or possible future technological developments.

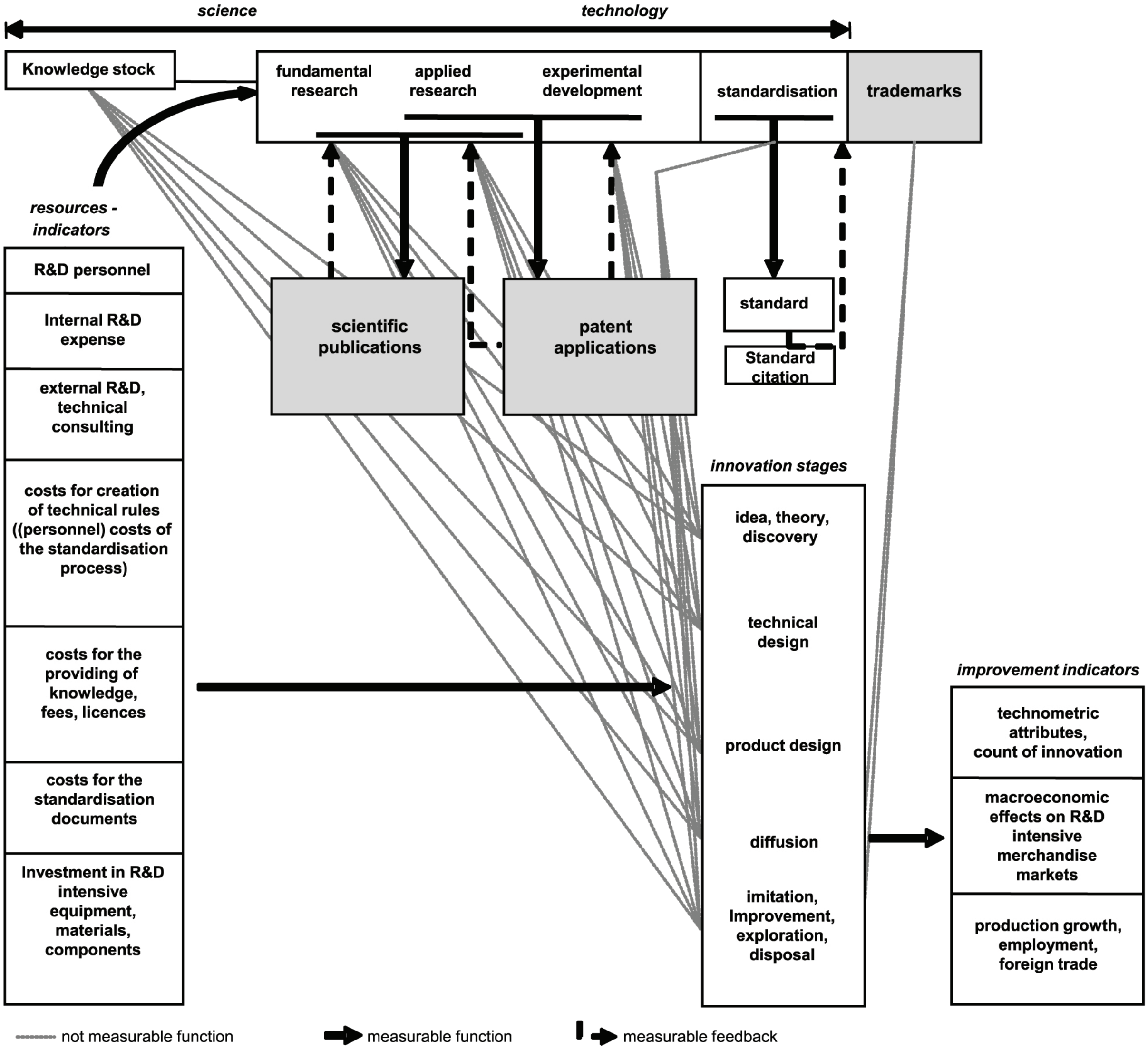
To yield analytical clarity, the analysis is usually based on a simplified phase model of scientific and technological progress (Grupp, 1990). Despite the R&D process being neither linear nor simple and the borders between the different phases being unclear and sometimes overlapping (Grupp, 1990; Freeman, 1982), general empirical evidence that support this simple model can be found. Nevertheless, S&T indicators must be seen as supplementary information (Grupp, 1990; Narin & Noma, 1985).

In the following, the slightly modified system of science and technology indicators introduced by Grupp (1997) is also referred to (see also figure 3.1). It adapts the concept of the linear phase model of the R&D process. Here, the R&D process differentiates between several research and development activities, from fundamental or basic research, applied research and experimental development to standardisation and market launch. These activities are related to different stages of innovations, i.e. idea generation, conceptual design, final design, engineering and diffusion, up to imitation. These sections are associated with different input and output indicators such as R&D expenditure, personnel, publications and patent applications, as well as trade and exports. Especially scientific publications seem to reflect fundamental and applied research (Grupp, 1990). For industrial development this is not consistently the case. Patent application data may be used for measuring applied R&D output, but measurement can be biased by innovator's patenting strategies (see Grupp (1990)).

Furthermore, the indicator system includes different stakeholders, who are positioned in the national innovation system (NIS). In the general introduction of the NIS concept (see Arnold et al. (2001); Carlsson et al. (2002); Fagerberg et al. (2006); Edquist (1997)), the innovation system includes all important economic, social, political, organisational, institutional and other factors that influence development, diffusion and the use of innovations (Fagerberg et al., 2006; Edquist, 1997). According to Fagerberg et al. (2006) this means that firms usually do not innovate in isolation, but in collaboration and interdependence with other organisations. The components are operating parts of the system, including the input/output system (i.e. the industry and business firms, suppliers, customers, competitors etc.), non-firm entities in science and technology, like universities and research institutes as well as technology policy in the form of government agencies and government policies (Carlsson et al., 2002; Fagerberg et al., 2006). In addition, the behaviour of organisations is shaped by other institutions and framework conditions such as laws, standards, rules, norms and routines, which constitute incentives and barriers for innovation.[2] In this paper the focus is put on national innovation activities. This includes all actors and activities of the economy which are necessary for indus-

[2] In fact, this system contains conceptual ambiguities, which are only briefly outlined in this paper. That is, institutions in the innovation system are used in different ways. They are sometimes used to refer to organisational actors like type of organisation or player, as well as institutional rules like laws, rules or routines. These different perspectives are described in Fagerberg et al. (2006) in more detail.

Figure 3.1: System of science and technology indicators, modified according to Grupp (1997).



trial and commercial innovation and which lead to economic development. Also the relationship between research, innovation and socio-economic development is important. One of the most important types of relationships in innovation systems involves technology transfer (Carlsson et al., 2002). The principal components of the national innovation systems are the industrial system, education and research system, and the political system and intermediaries (Arnold et al., 2001). As Arnold et al. (2001) states further, innovation and learning are seen more as network or collective activities. This conclusion contrasts an earlier conventional neo-classical view which focused on entrepreneurs as individuals. Therefore it is not sufficient to analyse only individual firms but also the system of networks within which companies operate. Foresight tries to contribute to this network; in order to allow good positioning of participants.

S&T indicators offer several analysis options for example analysis of the institutional set-up and the identification of R&D actors on the institutional micro-level is possible. Other options are analysis of technology trends on national levels, regional distributions of activities and actors as well as national specialisations (Grupp, 1990), citation analysis for the quantitative assessment of the performance of research (Butler & Visser, 2006) or identification of research groups using publication analysis (Calero et al., 2006). For a more detailed description on measuring innovation with S&T indicators and the analysis of publication and patent indicators as well as an introduction to the general methodology see Moed et al. (2004); Grupp (1990); Smith (2005).

3.3.2 Delphi technique

The Delphi technique is generally a kind of multilevel, structured group interaction process, in which individuals are required to give numerical judgements over a number of rounds. Between rounds, intermediate anonymous feedback is provided from the panel (Rowe et al., 2005). It is conceived to obtain consensual expert opinions or to identify needs for action in case of dissent.

Since its introduction in the 1950s (see Dalkey & Helmer (1962); Kaplan et al. (1949); Gordon & Helmer (1964)) the Delphi technique has become a widely used tool in a variety of disciplines (Rowe & Wright, 1999)] and all kinds of application areas to assess and predict future developments for measuring and aiding forecasting and decision making (Rowe & Wright, 1999). However, there is a large number of variations. Depending on the scope and objective of the survey, various elements of the classic Delphi designs, i.e. formalised questionnaires, anonymity of feedback, and iterative rounds (Woudenberg, 1991; Häder & Häder, 1998; Erffmeyer et al., 1986), are used. Originally designed for idea generation and evaluation, the Delphi method is a resource-efficient method, in reference to cost and time, to survey a wider circle of experts. During the first decade, the majority of Delphi efforts pursued forecasting purposes (Okoli & Pawlowski, 2004). Additionally, the method served not only as a tool for the detection of group opinions but also as a structure for the group communication process (Dalkey & Helmer, 1962; Linstone & Turoff, 1975; Bardecki, 1984).

Recent studies however consider the potential performance of Delphi and have demonstrated the validity and long-range accuracy of the Delphi technique (Häder & Häder, 1998; Okoli & Pawlowski, 2004). These studies investigate the determinants for precise predictions and accurate judgement. Though there is still discourse over the ideal design of the method, i.e. which elements lead to improvements in accuracy. At this juncture, especially the selection of panellists, optimal number of experts and survey rounds, nature of feedback, as well as accuracy and stability of judgements, were discussed. Nevertheless, the extent of the influence on the quality of the survey results is still uncertain. In the following, three of these aspects will be characterised in more detail.

(1) The optimal number of rounds: Reviewing several Delphi studies, Woudenberg (1991) found that in practical applications, the number of rounds varies from two to ten (see Riggs (1983); Clark & Friedman (1982)). To understand the mechanisms of reaching consensus in iterative rounds, empirical studies try to determine the optimal number of rounds for receiving stable and accurate judgements. Patenté & Anderson-Parenté (1987), Brockhoff (1975), and Rowe et al. (Rowe et al., 2005; Rowe & Wright, 2001) showed that judgemental accuracy generally improves over rounds. In an evaluation of Woudenberg (1991) nearly all investigated studies confirm this improvement. In addition, most improvement takes place between the first and the second estimation round (see Bardecki (1984); Nelms & Porter (1985); Dalkey (1969)). In some studies, accuracy further increased after the second estimation round (see Erffmeyer et al. (1986), where 4 iterations were needed). Yet convergence of opinion will not imply improved forecasting accuracy in every case (Rowe et al., 2005). Not all changes did improve predictions. False predictions in feedback, however, also have an influence on the response of the panels, which degrades the accuracy of the ratings (see Rowe et al. (2005); Scheibe et al. (1975)).

(2) The optimal type of feedback: Primary aim of Delphi is to reduce the conformity pressure (Rowe et al., 2005) exerted from majorities or dominant individuals. Any judgement change should be caused by new information only (Woudenberg, 1991). The effects of different types of feedback were investigated mainly by Rowe et al. (2005); Rowe & Wright (1996); Duffield (1993). This includes various types of feedback, such as statistical summaries of panel judgements, varying from a single number to complete distribution (Woudenberg, 1991) (see Jolson & Rossow (1971); Sahal & Yee (1975)) as well as reason feedback or arguments along with their numerical estimates (Rowe et al., 2005). The results of Rowe et al. (2005) show in particular those panellists who received reason feedback are more likely to be discriminative than those receiving statistical feedback. This means subjects are more likely to make changes to their forecasts with statistical feedback (Rowe et al., 2005). Woudenberg (1991) comes to a similar conclusion: A host of support can be found for the assertion that statistical feedback induces conformity. Nevertheless, Woudenberg (1991) challenges the correctness of this conclusion, since pressure to conformity is put upon individual panel members as well. On this, further studies deal with the question when and which experts change their opinion (see Patenté & Anderson-Parenté (1987); Rowe & Wright (1996)). To summarise, Rowe et al. (2005) showed iteration has more powerful influence on the accuracy than the feedback does.

(3) Selection of experts: More important than the first two aspects, however, is the right choice of panel members, since the quality of the Delphi results depends strongly on the expertise of involved experts. Therefore, Okoli & Pawlowski (2004)

as well as Delbecq et al. (1975) give some guidelines for identifying appropriate experts. Firstly, all relevant expert types were identified, considering all relevant disciplines, organisations, and academic and practitioner literature. Then these categories were populated with 10 to 18 individual experts (following the recommendations from Delphi (Okoli & Pawlowski, 2004)), which are invited to join the panel. This also requires an additional assessment of expertise of panel participants and raises the question of who exactly is considered an expert. Brockhoff (1975) proposes measuring expertise as an independent variable and giving two options for implementation. First, expertise ratings can be provided by third parties. Second, the determination of expertise can be carried out by self-rating, using ordinal scales. But even with this aspect, controversy still exists. The literature discusses difficulties of the self-assessment of expertise. Rowe et al. (1991) points out concerns about the appropriateness of self-rating as a true reflector of actual expertise. In addition, the need for experts is at the centre of the debate. Within this context, the relation between accuracy and self-ratings has been investigated, leading to opposite results (see Rowe et al. (1991); Parenté et al. (1984); Welty (1972)). It is hypothesised that experienced subjects are found more likely correct first-round predictions. It was also shown by empirical studies, that panellists with more expertise are less likely to change their initial assessment of the first round in the face of feedback by non-experts (Rowe et al., 2005; Patenté & Anderson-Parenté, 1987; Rowe & Wright, 1996). On the contrary, Woudenberg (1991) claims the lack of directly relevant information in uncertain situations determines judgements more than the available information. As a consequence, experts do not predict more accurately than non-experts. Nevertheless, it seems comprehensible to use experts in situations of high uncertainty.

Apart from these methodological discussions, the Delphi technique provides a cost-effective method to involve a variety of experts. Nevertheless, in addition to a variety of possible application errors (e.g. poor selection of experts can cause instability of responses among consecutive Delphi rounds), Delphi also has some general limitations (see Gupta & Clarke (1996); Landeta (2006); Linstone (1975)). The aim of the iterative questioning in consecutive rounds is to find a consensus, i.e. to reach certain estimation conformity. This consensus cannot be achieved for all future issues. This holds true in particular, if high uncertainty about the technological development exists. Dissent in evaluation results points out technological problems and increased need for discussion. In addition, the implementation of the Delphi method is highly dependent on the response rates of each round. The method is thus dependent on the willingness of experts to participate. Therefore, the motivation of experts is essential. Moreover, the control of irresponsible feedback, which will be given under the disguise of anonymity, can be difficult. This is especially true if panellists are interested in manipulation.

3.3.3 Role of standards and their economic background

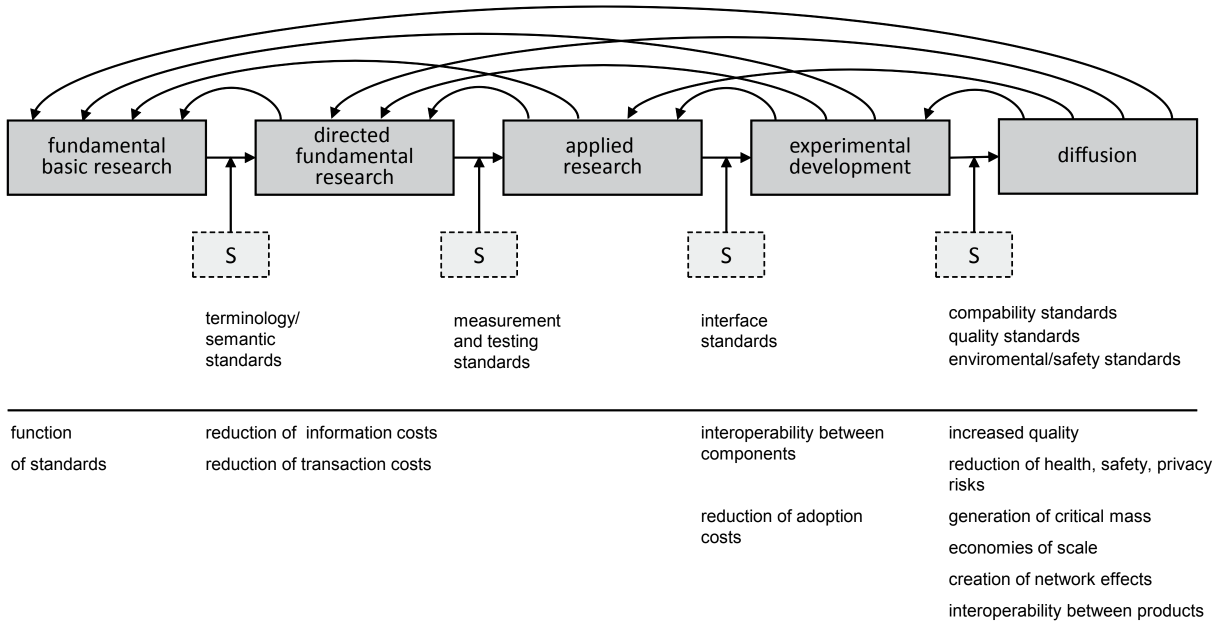
Standardisation is viewed as a decisive driver of innovations, which adds to the national economic development in a significant way. As shown in previous studies, standards play an important part in the R&D process of technological innovations (see Blind (2008); Blind & Gauch (2009); Swann (2000)). The details of the underlying conceptual background as well as economic assumptions about the role of standards in the R&D process can be found in Blind & Gauch (2009).

In short, different types of standards are linked to specific stages of the R&D process (Blind & Gauch, 2009) (see figure 3.2). For example, terminology standards are required in basic research for facilitating the communication within research communities, e.g. agreements for terminology and nomenclature to create a common baseline that is needed for global collaboration and understanding of nanotechnology.[3] In such emerging fields of science and technology, standards are necessary to allow efficient communication between researchers and to build the basis for all following phases in the innovation cycle and the following standardisation processes (Blind & Gauch, 2009). Furthermore, they simplify the transfer of knowledge from basic to applied research. For this, transfer measurement and testing standards are needed, which allows the progress towards product-related developments. Interface standards then facilitate the interoperability of components and act as an intermediary between applied research and experimental development. Compatibility standards ensure the interoperability between products, facilitating the transition of prototypes into mass markets. This concludes with quality standards, which guarantee safety requirements for the product. These different types of standards are also linked to economic functions. For instance, terminology or measurement and testing standards lead to a reduction in transaction costs, according to Swann (2000). More economic functions can be shown, i.e. the contribution to the increase of quality, the reduction of potential health risks, and the generation of critical mass of products. This can help to eliminate doubts in consumers' purchase decisions.

However, a far more important aspect is the diffusion of technological knowledge through de-jure standards and technical guidelines. Standards are considered to be necessary for the economic development of a technology, i.e. they promote economic growth (Blind & Jungmittag, 2008). As Blind (2002) showed, standardisation conducted by acknowledged standardisation bodies is similarly important to other diffusion channels like imitation, licensing, R&D cooperation and the commercialisation of new products. As a consequence, the output on national standardisation activities in the form of the publication of new standards can be viewed as an indicator of the diffusion of technological knowledge. As part of the technical, economical infrastructure (Tassey, 2000), de-jure standards and technical guidelines contribute significantly to the international competitiveness of entire industries of a country

[3] See website of the American National Standards Institute ANSI: http://publicaa.ansi.org.

Figure 3.2: Standards in the research and innovation process (see Blind & Gauch (2009)).

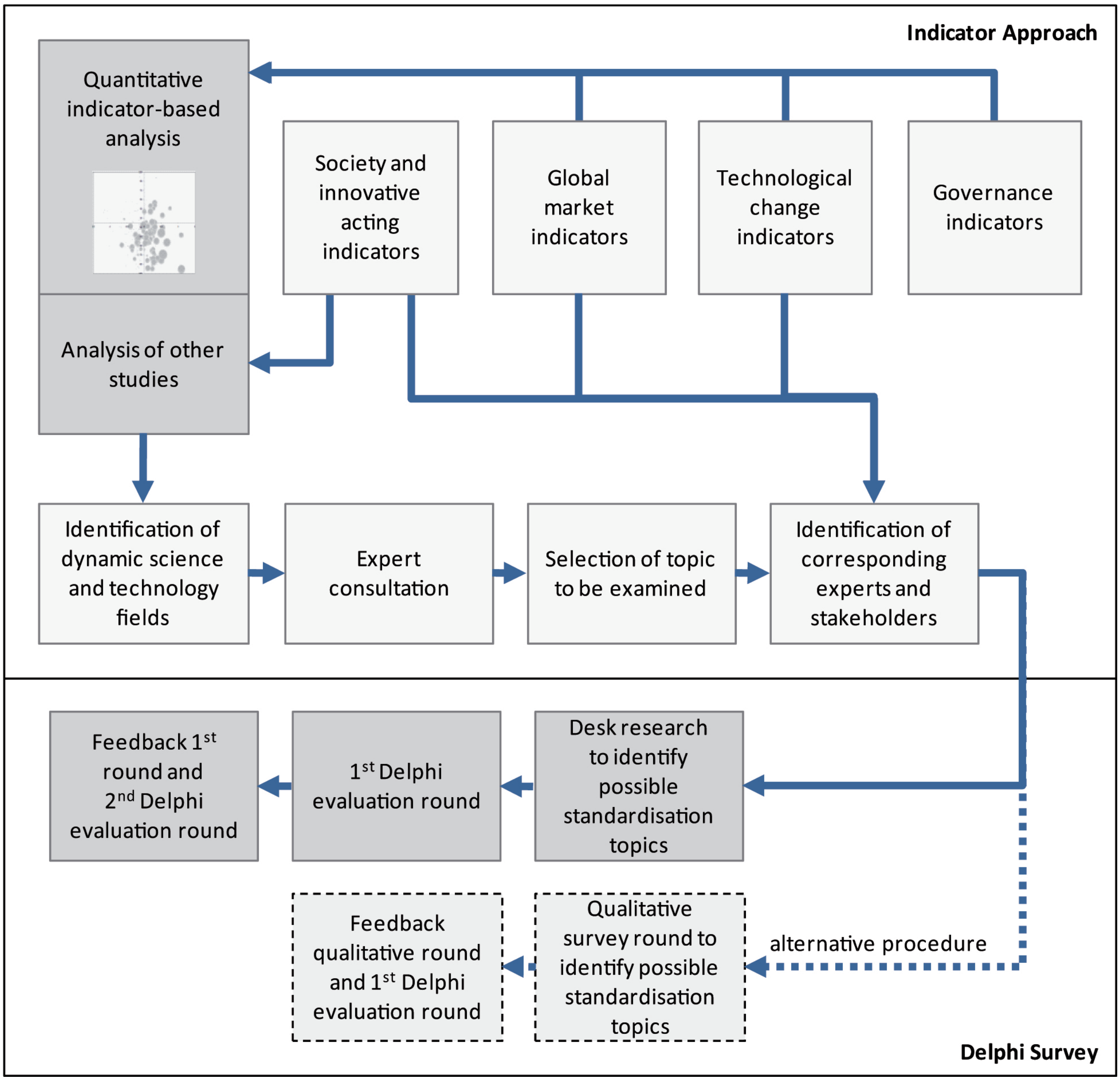


by affecting economic growth and foreign trade, see Swann et al. (1996); Blind & Jungmittag (2005). Additionally, by facilitating the coordination across different communities which follow a similar technological paradigm, standards can channel different developments of new technologies. Especially in complex research areas, heterogeneous participating communities and different subareas of scientific and technical activities are involved. In such cases, standardisation results cause a reduction of technological fragmentation and consequently the stabilisation of a technological paradigm, adding to the diffusion of one technological solution (Gauch, 2006).

3.4 Combination of methods

In this section the methodological supplement to the Delphi technique will be described in more detail. In general, it allows systematic exploration of future scientific and technological developments. For this purpose, quantitative indicator-based analyses and qualitative in-depth Delphi surveys are combined. Thus, the foresight approach is divided into two main components, the indicator approach and the Delphi approach. The indicator part supplements the traditional Delphi survey in two points. First, it allows the analysis and identification of technological developments. On this, statistical analyses of several indicators are conducted to examine the entire research and technology landscape e.g. of a country. After this general exploration of macro trends, specific topics have to be selected. Here, more detailed Delphi surveys will be carried out subsequently. Secondly, bibliometric information of indicator data provides useful information for the identification of necessary experts, which can be invited to participate in the Delphi panel. The method is generally suitable for all foresight applications which aim to analyse several parallel technology developments. The sequence of individual steps of the approach is illustrated in figure 3.3.

Figure 3.3: Sequential steps of the approach.

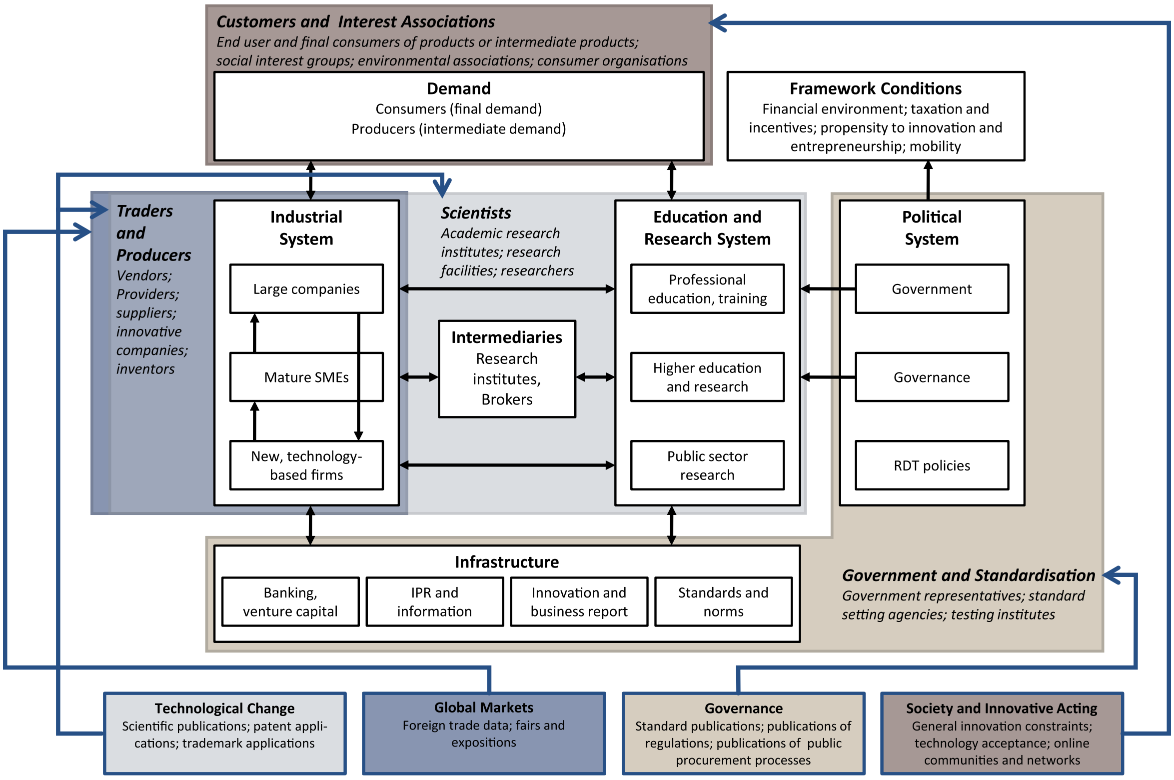


For the indicator approach, a number of indicators and analysis options are possible. Depending on the foresight issue appropriate indicators and analyses should be selected. Here, especially such indicators, which facilitate the identification and comparison of more general dynamic future technological developments in various disciplines, are suitable. These include indicators that allow statistical analysis. This is ensured by criteria such as long time series, possible geographical comparisons e.g. for countries, good database availability, detailed classification of sub-topics, and availability of data accessed via databases. The set of indicators should also provide information for the identification of experts. Many of these indicators are available in corresponding databases, which can be evaluated for this purpose.

The selection should also consider following aspects: In regard to the selection of suitable panellists, Häder (2000) recommends that the population of Delphi experts should be selected from all relevant domains of the foresight issue. In the described case, this concerns all relevant stakeholders of standardisation, which can be captured by the national innovation system. Different drivers of standardisation processes are considered. They arise from science, R&D, industry, demand and the public sector. Hence, participants in standardisation come from R&D, product development, marketing and sales, operations, system integration, consultancies and government representatives (de Vries et al., 2003). The DIN German Institute of Standardisation also includes stakeholders from the consumer-side, trade, science, government, testing institutes and industry. In addition, representatives of relevant establishments for customer interests, like consumer organisations (end user and final consumers of products or intermediate products), and other interest associations, such as environmental associations, professional associations and unions, not yet active in standardisation should be included. In addition, government representatives, standard setting agencies and testing institutes should be included. To match this range of stakeholders, a wide range of associated indicators or even desk and internet researches have to be used. The assembled system of indicators can be summed up into four major categories: Technological change, global markets, governance and society as well as innovation. Figure 3.4 combines the diagram of the actors and stakeholders of standardisation in the national innovation system (see Arnold et al. (2001)) and the chosen indicators.

In the first category, important output indicators are listed. On this, publications in scientific journals, patent applications and trademark applications to describe technological development and change are included. Here, scientific publications characterise activities in basic or fundamental research. Patent applications cover the performance in applied research and development. Trademark applications provide an indicator for the market launch of product and services innovations. The second category covers indicators to specify global markets and includes macro data, e.g. foreign trade data and company participation in international fairs and expositions. The third category brings together governance indicators, such as publications of existing standards for basic evaluations of the demand. Also included are publications of regulations and the regulatory framework, i.e. the complementary standardisation need on the policy side, and publications of public procurement applications in order to extend the demand perspective. According to Martin (1995), the criteria for selecting promising foresight areas include not just economic but also social benefits, such as health, quality of life, environmental protection and contributions to culture. Therefore, aspects of society are included as well, because standards promote the diffusion of innovation and also affect acceptance of users. Thus, the fourth category comprises of survey-based society indicators, such as

Figure 3.4: *National innovation system and the different stakeholder of standardisation with their indicators, modified according to Arnold et al. (2001).*



general innovation constraints and the technological acceptance on the demand side as well as online networks and communities.

For the analysis, comparative rates and growth rates for different subject fields were calculated to measure the specialisation of a country and the dynamic of field actors, respectively. More precisely German specialisation indicators and Sharpe ratios were calculated. This includes the listed indicators of category 1–3. The results of the German portfolio were compared to activities in the international landscape. Detailed information on the exact calculation of the specialisation indicator and Sharp ratio can be found in Soette & Wyatt (1983); Noyons et al. (1998); Engelsman & van Raan (1993); Sharpe (1998). However, other analyses can also be used at this point (see examples in section 3.3.1). For the remaining indicators of category 4, other studies and surveys were consulted.

3.5 Results of exploratory case studies

The approach was developed in the context of a research project. The application was tested on several case studies. Through detailed analysis of the selected indicators sets, as described in the previous sections, different dynamic fields of science and technology could be identified. As shown by Blind (2002, 2004), these fields also require an increased need of future standardisation work. In the following the exploratory results from the conducted surveys are to be discussed in a comparative analysis.

3.5.1 Data description and indicator results

Between 2006 and 2009, ten subject areas with growing scientific and research activities were investigated, including Nanotechnology, Safety Technology as well as Medical and Biotechnology in 2006/2007, Efficiency of Resources and Maintenance Services in 2007, Measuring Instruments and Energy in 2008/2009, as well as E-mobility, E-energy and Optical Technologies in 2009. The selection of these topics was based on various criteria, including the national specialisation, apparent dynamic developments over the last few years as well as the comparison with the international development. For the final selection, experts of the national standardisation organisation in Germany (DIN) were involved. The following table 3.2 provides both initial and final number of potential fields with respect to each indicator. For space-saving reasons, not all of these identified subject fields are illustrated, only the subjects of final Delphi surveys are listed. As the results in table 3.2 show, especially subject areas that can be identified through various indicators have been selected for detailed analysis.

To evaluate necessary standardisation topics, different stakeholders of standardisation had to be identified. On this, keyword searches were conducted. It was assumed that for example researchers, who publish in a specific subject area, could be designated as experts. Using these keywords, a systematic survey of all the German players was conducted. All persons identified in this way were contacted through e-mail or letters. Some experts were also convinced to join the panel by telephone.

Panellists were identified mainly through scientific publications and patents, but also via standards committees and federal ministries, internet network, index of exhibitors, and databases of companies. In fact, such systematic investigation is very extensive, however bibliometric information in these databases offer opportunities to evaluate them effectively with the help of software support. Table 3.3 shows for which indicators panellists could successfully be identified and interviewed. This includes (1) scientists, inventors, companies and organisations in R&D, companies in product development and service, (2) international trading companies, (3) stakeholders active in standardisation, governmental representatives, companies, research institutes, testing agencies, standard setting organisation, and (4) members of online communities and networks. In the last column panellists are summarised, which could be identified via targeted internet searches in research institutes and government agency as well as forwarded questionnaires.

Table 3.2: Indicator set and identified subject fields.

Measure	Level	Initially analysed fields	Number of identified specification fields and relevant examples
Scientific Publications			
1	1	26 academic domains aggregated from the subject categories of SCI[1]	6 fields including Medical Engineering, Materials Research and Optics
1, 2	2	229 subject categories of the SCI[1] and the SSCI[2]	48 fields including Biochemical Research Methods, Biomedical, Engineering, Biomaterials and Material Science, Crystallography, Environmental Studies, Instrumentation, Material Science - Coating and Films, Multidisciplinary Material Science Nanoscience and Nanotechnology, Neuroimaging, Optics, Radiology and Medical Imaging as well as Spectroscopy
Patents			
1	1	44 economic sectors aggregated from the patent classes of the IPC[3]	25 fields including Paints and Coatings, Electrical Motors, Electricity Distribution, Process Control Technology
1	1	38 areas of high technology aggregated from the patent classes of the IPC[3]	15 fields including Electrical Motors, Electricity Distribution and High-Quality Instruments
1, 2	2	129 patent classes of the IPC[3]	7 fields including Machine Tools, Instrumentation
1, 2	3	615 subclasses of the IPC[3]	16 fields including Cleaning, Maintenance, Repair and Cleaning Services of Vehicles also Wind Power Generation
Trademarks			
1	2	16 categories aggregated from the Nice[4] classification	6 fields including Machinery and Repair Services
Foreign Trade Date			
1	1	25 economic sectors	6 fields including Medical and Measurement Engineering, Process Control Technology and Optics
1	1	11 service industries	3 fields
Standards			
1	2	40 classes of the ICS[5]	6 fields including Imaging Techniques and Mechanical Engineering
Regulation			
1	1	19 categories of European guidelines	4 fields
1, 2	1	13 categories of national guidelines	5 fields
Public Procurement			
1, 2	2	44 public procurement classes of the CPV[6]	7 Fields including Measuring Instruments, Electrical Motors and Electricity Distribution
Technology Acceptance			
		Surveys: Eurobarometer, community innovation survey (CIS)	14 Fields including Solar Energy, Biotechnology and Genetic Engineering, Nanotechnology, New Energy Sources to power cars, Energy Saving Measures in the Home

Measures:
1 Natonal specialisation index for Germany
2 Growth rates

Aggregation Level:
Level 1 Classification aggregated to sectors or scientific disciplines
Level 2 Aggregation according to the 1st or 2nd level of classification
Level 3 Aggregation according to the 3rd or 4th level of classification

Abbreviations:
[1] SCI – Science Citation Index
[2] SSCI – Social Science Citation Index
[3] IPC – International Patent Classification
[4] Nice Classification – International classification of goods and services
[5] ICS – International Classification for Standards
[6] CPV – Common Procurement Vocabulary of the European Union

Table 3.3: Panel composition according to the indicators (results of the first evaluation round).

	Scientific publications, patent applications, trademark applications	International fairs and expositions, company databases	Standardisation committees, publication of public procurement	Online communities and networks	Targeted search or forwarding
Nanotechnology	21%	26%	1%	52%	–
Safety Technology	44%	55%	–	–	1%
Medical and Biotechnology	69%	28%	3%	–	–
Efficiency of Resources	51%	–	45%	–	4%
Maintenance Services	50%	47%	–	–	3%
Energy	15%	7%	73%	5%	–
Measuring Instruments	39%	18%	41%	2%	–
E-mobility	27%	–	13%	27%	33%
E-energy	53%	–	10%	11%	26%
Optical Technologies	45%	–	17%	34%	4%

3.5.2 Delphi results

To map the consensual nature of standardisation processes, at first two subsequent Delphi evaluation rounds were conducted. For this purpose, corresponding standardisation topics had previously been researched and then set for evaluation. However, the determination of these issues provided a number of challenges, since the various topics should represent the different perspectives of all heterogeneous stakeholders. After the first evaluation round, the results were compiled in form of statistical feedback. The panellists then had the opportunity to verify and change their judgements in the second evaluation round. The preparation of these topics requires e.g. a high level of technical expertise prior to the survey. For this reason, the survey was supplemented by an additional open and qualitative survey round. This provided an additional opportunity for the stakeholders to highlight recent and important issues. After this qualitative round the topics were clustered to a condensed final list. This list was the basis for the subsequently first evaluation round.

The evaluation rounds started with the assessment of the panel expertise. Panellists were asked, according to the recommendation of Brockhoff (1975), to give individual self-ratings of their expertise of each topic. Here we worked with a scale of real numbers graded from 1 to 4. Panel members, who rate their own expertise with medium to high level, will be in the following referred to as experts. In addition to the assessment of expertise, the experts were asked to evaluate the timing of such standardisation activities; the importance of the topic along various dimensions, including also the type of standard required and its level of enactment (see figure 3.5). The statistical analysis of these ratings resulted in the prioritisation of relevant and urgent standardisation issues.

Figure 3.5: Questions per topic (Delphi survey of 2009).

	Expertise on this topic				Time period for stansatdisation activities					Importance for the …						Type of standard						Level of enactment		
	No expertise	Low expertise	Medium expertise	High expertise	Already started / planned activities	2010-2012 (1-3 years)	2013-2015 (4-6 years)	2016-2018 (7-10 years)	Later than 2018		Technological development	Economic development	Environment	Health	Safety	Terminology and classification standards (nomenclature)	Standards for measuring and testing technology	Quality and safety standards	Compatibility standards	Product and service standards	No Standard	National	European	International
										++	○	○	○	○	○									
Standardisation issue	○	○	○	○	○	○	○	○	○	+	○	○	○	○	○	□	□	□	□	□	□	□	□	□
										o	○	○	○	○	○									

Besides the additional qualitative round, another significant change in the execution of the Delphi survey was made: It was decided to skip the second evaluation round. From a practical point of view several aspects were decisive. The evaluation of the first three surveys had revealed that there was no significant decrease in variance between the first and second evaluation round. Further investigations to determine the degree of consensus of each topic also showed no decrease of dispersion. For this purpose, the distances between the 3rd and 1st quartile were considered. More feedback-evaluation loops will improve the accuracy and the degree of consensus, but it has to be noticed, that experts change their opinion less frequently than non-experts. Further exploratory analyses showed an increase of the percentage of experts in the second round, i.e. non-experts often do not participate in the second rounds of the survey. The results also indicate that the more experts are involved, the greater the variance of answers is. In addition, panel members with less expertise do not estimate further questions on same topic, e.g. due dates for standardisation activities.

For this, the number of people who self-rated their expertise but do not give estimation on the time priority of standardisation processes, was calculated:

$$n_{non-expert} = [n_{expertise} - n_{time}]. \tag{3.1}$$

First evaluations of this number show that participants are more likely to complete the questions, which they can evaluate. For the final decision to change the sequence of the Delphi survey, these various pro and con reasons were weighed. Deciding factor for the decision to skip the second evaluation were above all practical considerations. The drop-out rates diminished considerably the significance of the survey. Therefore, the other surveys are not Delphi surveys in the strict sense. Nevertheless, all survey results should be used to evaluate the applicability of the indicator approach.

Table 3.4 highlights the basic results of the investigated subject fields, including the number of panel members, drop-out rates, number of topics per subject field, as well as the average number of experts per subject field.

Table 3.4: Key data of the Delphi surveys.

	Number of identified and contacted persons	Number of participants in qualitative round	Number of participants in 1st evaluation round (N)	Number of participants in 2nd evaluation round
Nanotechnology	1501	–	95	49[1]
Safety Technology	935	–	39	21[1]
Medical and Biotechnology	473	–	48	20[1]
Efficiency of Resources	2333	40	94[2]	–
Maintenance Services	336	31	25[2]	–
Energy	1530	24	64[2]	–
Measuring Instruments	1386	25	54[2]	–
E-mobility	2488	74	15[2]	–
E-energy	2488	74	19[2]	–
Optical Technologies	3877	66	53[2]	–

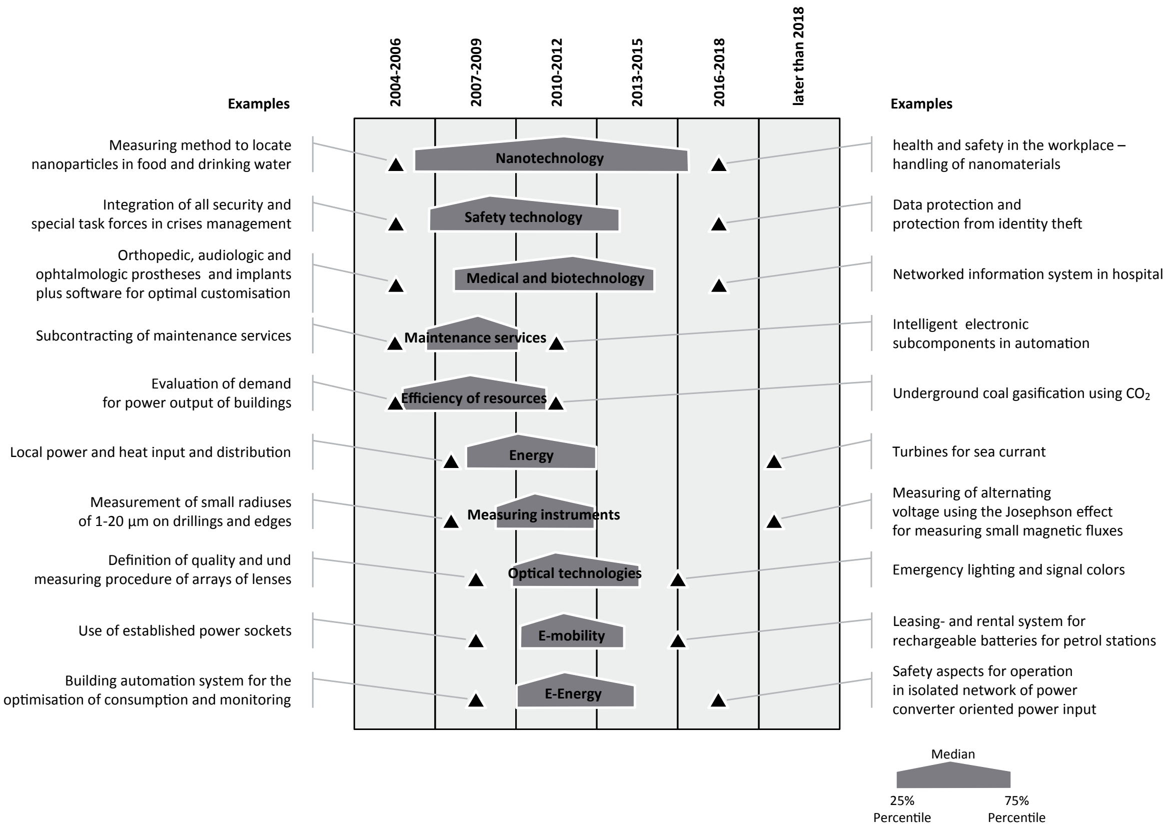
(1st evaluation round, in %)	N	Average number of participants per topic Q1: expertise [min, mean, max]	Average number of participants per topic Q2: time period [min, mean, max]	Average number of experts per topic [min, mean, max]	Number of participants without standardisation background
Nanotechnology	95	[3, 80, 97]	[0, 37, 77]	[6, 35, 100]	60
Safety Technology	39	[0, 72, 90]	[0, 18, 56]	[0, 15, 54]	26
Medical and Biotechnology	48	[77, 85, 94]	[6, 19, 58]	[0, 18, 51]	38
Efficiency of Resources	94	[64, 77, 88]	[16, 28, 52]	[5, 34, 67]	41
Maintenance Services	25	[60, 76, 96]	[12, 44, 88]	[6, 48, 83]	20
Energy	64	[61, 69, 83]	[5, 14, 38]	[0, 18, 47]	15
Measuring Instruments	54	[63, 72, 87]	[2, 13, 33]	[3, 14, 38]	36
E-mobility	15	[47, 67, 93]	[0, 33, 60]	[0, 29, 60]	20
E-energy	19	[53, 68, 95]	[11, 37, 74]	[0, 31, 71]	5
Optical Technologies	53	[58, 68, 81]	[4, 11, 28]	[0, 11, 41]	31

[1] Only participants of the first evaluation round were contacted again
[2] All identified persons were contacted again

To illustrate the different characteristics of the science and technology fields, figure 3.6 shows the average time period for the standardisation in the subject areas. Additionally, table 3.5 in the appendix summarises all studied subjects in detail.

The subject fields in figure 3.6 are specified by three statistical characteristics: The average value of the estimation is indicated by the median; the variance is displayed by the 25 and 75 percentiles. In order to provide an insight into the diversity of standardisation topics, the figure shows both examples of lower and higher pri-

Figure 3.6: Average time period for the standardisation in the different subject area.



ority. Issues with higher priority can be found on the left side of the figure, subjects with lower priority on the right. The topics of Nanotechnology, Safety Technology and Medical and Biotechnology include a broader scope on substantive topics than the other subject areas. Here, we also considered application issues of the technologies. Furthermore, for an accurate comparison of the different time periods, however, the different survey dates had to be taken into account, ranging from 2006 to 2009. Nevertheless, the topics of Resource Efficiency were characterised by a high priority in time. This is also reflected in the evaluation of standardisation types. For Efficiency of Resources as well as the subject of Energy all standard types are required.

The different types of standards play a very specific role in the various phases of the research and innovation process. Depending on the current stage of science and technology, the required standardisation activities have to be initiated by collecting the relevant stakeholders in these processes (Blind & Gauch, 2009). Along with the ratings for the standardised type, the assessment of the standardisation period represents the technological development in the field. Looking at the example of Nanotechnology, the results of the survey and recent investigations can be combined into a special field characteristic. According to the experts, standards for measurement and testing technology, as well as quality and safety standards are especially required. The latter become more relevant when risky, in our case nanotechnology products, are first introduced to the market (Blind & Gauch, 2009). Together with the number of foundations of new working groups for existing or new technical committees, and the indicator results on currently published standardisation documents between 2003 and 2006, a trend towards applied development can be seen.

For the other topics, the following assessments were made: The results for Security Technologies reflect a high demand for standard classifications, especially for terminology standards. This can be explained by the high complexity and variety of involved communities. In Medicine and Biotechnology as well as E-energy, primarily a need for quality and safety standards as well as compatibility standards could be determined. Not surprisingly, in the case of Maintenance Services in particular, standards for products and services were dominant. That was true for Measuring Instruments, too. Here, measurement and testing standards as well as compatibility standards were demanded. For optical technologies other terminology and classification standards as well as compatibility standards are necessary. For the three remaining Energy issues, the greatest need was estimated. This in particular concerns terminology and standards for classification, measurement and testing standards, also standards for products and services for the topic E-mobility. Finally, for Efficiency of Resources as well as Energy all standards are needed. These results show a connection between the subject area, the industry standard type and the technological development of the subject.

This relationship is also reflected in another question of the questionnaire. In this case, the experts were asked to rate the general potential of standards. Depending on the subject, this resulted in different priorities. For the subjects of Nanotechnology plus Medicine and Biotechnology the potential of de-jure standardisation lies in the improvement of cooperation between researchers and developers. The results for topic of Measuring Instruments show similarities. Although the estimates are not as high as in the first two issues, they apply here as well. Moreover, for Measuring Instruments and E-energy standardisation activities are considered to be the necessary basis for future research and development. This also applies for Security Technologies, Optical Technologies and E-mobility. For the experts in Resource Efficiency standards can offer legal certainty. For the topic of E-energy, standardisation is the solution for specific technical problems. Both aspects are also relevant to the issues of Energy and Maintenance Services.

Due to the international orientation of some technology areas, standardisation activities no longer make sense at a national level. Although some aspects of the areas of Security, E-mobility and E-energy are, according to the expert opinion, of national relevance, the majority of standardisation issues should be addressed at the European and international level.

3.6 Discussion and conclusions

In this paper, a possible effective, methodological supplement for classical Delphi approaches to involve more and a larger variety of experts has been introduced. The combination of acknowledged quantitative indicator-based analyses with qualitative in-depth Delphi surveys provides systematic forecasts on future fields of science and technology developments. As all Delphi surveys, the introduced supplementary approach also depends on reliable expert evaluations in order to identify relevant issues. Thus, it depends on the appropriate identification of experts. Nowadays, the landscape of actors and institutions in science and technology becomes more and more unclear due to new actors form emerging countries entering the scene. In addition, especially radical developments in science and technology emerge at the interfaces of different science disciplines and in converging technologies. Consequently, the challenge of identifying the "right" experts is increasing. Here, the analysis of bibliographic information facilitates the identification of necessary actors and stakeholders. This requires an issue-oriented set of indicators as well as accurate preliminary investigations of appropriate stakeholders. Hence, Delphi experts should be selected from all domains relevant for the future of the specific issues. The method is generally suitable for all foresight applications aiming to analyse technology developments. Nevertheless, a simple transfer of the methodological approach to other application areas is not enough. The implementation will require some adjustments to the indicator set, e.g. adjustments to the required stakeholder groups, to ensure adequate foresight results.

Preceding qualitative survey rounds also offer the possibility to collect topics from the corresponding expert community, i.e. references of recent scientific findings. Moreover, the aggregation of these specific topics requires some additional effort. In addition, the introduced approach is suitable for identifying respondents with the necessary expertise. Depending on the subject area and the specific topic in the conducted surveys, the average of 14 to 48% of experts with high expertise could be identified. There is also a number of issues for which none of the identified stakeholders possessed technical expertise, even if these issues were the result of the qualitative survey round. This indicates that in these areas only few experts are obviously active. In new and emerging fields, sufficient experts might not be available to provide their technical knowledge. The more specific the foresight issue, the smaller the circle of available experts. In this case, the chosen approach can meet its limits.

On this, alternative methods may help to identify suitable experts with desired attributes. Here methods like the so-called snowball approach were used. Starting from a small number of individual experts, other experts can be identified with the help of new contacts. This approach, however, requires considerable time and research efforts. Therefore, in some cases it may be suitable to narrow the possible alternatives down. This is especially true when desired attributes are very rare. In such cases, approaches exist to improve the snowball systems, i.e. reduce the screening costs. For example, there is the approach of von Hippel et al. (2009), which is also a kind of snowball system in which only experts with higher expertise were recommended. It seems suitable for identifying the most renowned experts of a subject area. In addition, software programs offer easy ways for bibliometric analysis to complement such simple screenings as presented. Network analyses provide similar scopes of application. A closer look at the indicator set shows there are more indicators on the technology push side. Even though it is much more difficult to select stakeholders from the user and even the consumer side, there is a need to extend the methodology towards these indicators. The same is true for representatives of public organisations and regulatory bodies. Also simple quantitative approaches, as described in this approach, are not sufficient to characterise the developments of specific technologies in subject areas. Here, the indicator data includes more information on the state of the art in science and technology as well as additional micro-data. This provides further information about content relevant developments. This information, collected systematically, might also help to identify potential new fields of science and technology. To study the general technology development and to identify important research communities, other methods and tools, like text mining for the analysis of word frequencies and co-occurrences for the evaluation of content proximity, as well as citation analyses may be helpful.

In preliminary analyses, only a few and unsystematic foresight experiences regarding future priorities for regulations and standards could be identified (Blind, 2008). Although the Delphi technique has many similarities to the standardisation process, there is a lack of relevant applications in this field so far. Even if the application of the Delphi method provided some practical issues, the rarely used Delphi technique in combination with an indicator-based approach proved suitable for this novel application area. As already explained, experts change their opinion less frequently than non-experts. For the general evaluation of the applicability of the Delphi method for standardisation foresight, the approach therefore relies on the hypothesis that panel members with high expertise give more correct first assessments compared to non-experts (see Woudenberg (1991)). Despite the practical issues, e.g. low response rates, this assumption speaks for the applicability of the method. From a methodological point of view, the Delphi technique improves estimation accuracy and the level of consensus, as long as the method is appropriately applied. For the application of the Delphi approach, practical considerations should be considered, too. It should be noted that the Delphi method does not provide per se a consensus. This is particularly true with issues of high uncertainty. Divergence shows crucial conflicting areas, indications for an increased need for discussion or technical problems. In cases where the level of detail is very high, connections and similarities between individual respondents might only be comprehensible by very few experts. Thus, the chosen approach allows the identification of very specific future standardisation issues and issues that currently lack consensus. The major aim of this investigation was not to predict the accurate time of occurrences, but to identify priorities to start standardisation in specific topics. The implementation problems are caused by the topic of standardisation itself. As in normal standardisation processes, surveys focusing on standardisation, meet similar barriers for the participation. Here, especially the lack of knowledge, time as well as transparency in the structure and the development of standard procedures, are decisive reasons for not participating (de Vries et al., 2003). Therefore, the goal of this investigation was to raise the awareness of the relevance of standardisation among relevant stakeholders. Furthermore, in contrast to the classical Delphi approach with a long-term perspective of up to 25 years or longer, the standardisation foresight focuses on shorter periods. The time period mainly depends on activities that should be planned in the next 10 years.

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Table 3.5: Overview of the studied subjects.

Nanotechnology	Safety technology	Medical and biotechnology
• Nanoparticles, nano-powder and nano-coatings • Measurement, analysis and testing • Effects on health • Impact on safety • Environmental concerns • Product and process standards • Field of application: Food • Field of application: Biotechnology, medicine and cosmetics • Field of application: Information and communication technology and electronics • Field of application: Materials Research • Field of application: Car industry • Field of application: Agriculture Supplements • Supplements	• Crisis management • Sensors and detectors • Algorithms, simulation • Biometric security technology • Authentication • Privacy, protection against misuse of information • Information and communication • Security of goods • Transport and mobility • Personal protection • Medical health • Environment and civil protection • Supplements	• Medical diagnostic computer-aided diagnosis • Therapy planning and therapy monitoring • minimally invasive surgery and intervention • Medical technology for regenerative medicine • Modeling and simulation • E-Health • Robots • Other medical equipment and supplies • Drug development • Microsystems and microelectronics • Nanotechnology • New Materials • Hygiene and safety • Medical services
Efficiency of resources	**Maintenance services**	**Measuring instruments**
• Maintenance management • Core processes of the industrial services business • Inspection, maintenance and repair services • Repair and maintenance services for vehicles • Supply of spare parts, spare parts management, operating and auxiliary materials • Maintenance and repair systems for example Condition monitoring, machine diagnostics, mobile and remote maintenance • Measuring and monitoring equipment, sensors and automation technology • Safety	• Technologies for resource-efficient power generation • Substitute and renewable energy • Waste treatment, waste water treatment, prevention, recycling and recycled • Materials and energy from waste • Industrial processes and product development • Households and marking of terminals • Water and waste water systems • Building Construction	• Cameras and sensors for testing and measuring of physical properties • Procedures and analysis • Navigational, meteorological, geological and geophysical instruments • Interfaces and communication • Field of application: Automotive • Field of application: Optics, coatings, finishes • Field of application:Building construction
Energy	**Optical technologies**	**E-mobility**
• Energy • Energy balance • Engines, energy converters and fuel • Energy storage • Electric motors, generators and transformers and other components • Energy Harvesting • Compressors and pumps • Circuit elements • Electric cables, pipes and wires	• Lighting and lamps • Building, outdoor and track lighting • Safety and warning lights • Display and display technologies • Optical measuring and sensor technology • Requirements for measurement • Optical measuring and sensor technology in robotics, aerospace • Manufacturing and production technology • Optical medical and health technologies • Information and communication technology • Vehicles • Coatings	• Drives • Electrochemical energy storage • Engine components • Resource-efficient vehicle components Power supply and network infrastructure elements • Energy-optimising driver assistance systems • Safety and security components • Fuel cells
E-energy		
• Decentralisation of energy production • System Management • Energy transport networks • Energy storage and conversion • Energy measuring equipment at the producer level • Measuring devices at the retail level • Consumer equipment • Alternative energy		

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4 Supporting Successful Standardisation Processes in Complex Emerging Fields through Quantitative Analysis – The Case of Nanotechnology

Abstract
The field of nanotechnology like other emerging technologies is characterised by its rapid development and a multitude of participating communities and different subareas of scientific and technical activities, challenges regarding the understanding, coordination and implementation of new technologies. By reviewing some of the main challenges for successful knowledge-based standardisation in complex emerging and heterogeneous fields, this paper will present a range of quantitative methods, to identify and foster the integration of topics and researchers in such research fields that can be decomposed into thematic subfields and present solutions for an integration of this plurality into standardisation processes. To provide a methodical approach for further foresight activities in complex R&D fields we display possible results for the example nanotechnology and their practical policy implications.

Keywords
Standardisation process, foresight, quantitative analysis, nanotechnology

Contents

4.1 Introduction

Emerging research areas, like the field of nanotechnology, with its multitude of heterogeneous participating communities and different sub areas of scientific and technical activities, provide various challenges to coordination and the implementation of new technologies. While a high degree of diversity in types of actors, heterogeneity of preferences or incommensurability of technical and scientific aspects and paradigms might not present a problem in the short run – some fields may well benefit from plurality and variation over a short period of time – in the long-run, i.e. in the case of co-modification of the research results, an excess of plurality, when not properly integrated into a larger context, may result in inefficiencies in the market and lack of coordination.

Through standardisation, technical and social closure of discourses can be achieved leading to a reduction of complexity and reduction of fragmentation and consequently to stabilisation of technological paradigms. Still, the relationship between complexity in the realm of research on the one hand and standardisation on the other hand is more complicated than the mere function of standardisation, i.e. the reduction of complexity, might suggest. Even though standardisation can reduce complexity the chances of successful standardisation decreases with increasing complexity, i.e. in cases where standardisation has, due to the complex nature of a technical field, the most impact on technical change, it is most difficult to carry out. As a consequence, standardisation in complex technical fields is subject to a number of challenges. As an example for a complex technical field, nanotechnology will be used in the analysis to point to some of these challenges and how standardisation foresight can ameliorate some of these challenges.

By reviewing some of the main challenges for successful knowledge-based standardisation in complex emerging and heterogeneous fields, this paper will present a range of quantitative methods, which can support the identification of the underlying structural layers of complex scientific topics and communities to point out possible fields of action in standardisation. Based on this methodical approach, a blueprint for further standardisation foresight activities in complex R&D fields will be provided. More precisely, the issue of identification and integration of both topics and researchers for the case of large complex research fields, which can be decomposed into thematic subfields, will be addressed. Three possible ways with different levels of detail to discover the underlying structure in complex emerging technologies using retrospective data will be considered.

4.2 Motivation and literature review

The case of standardisation in complex fields as well as the necessity for standardisation foresight can basically be argued by taking two fundamentally distinct perspectives into account. One perspective highlights the non-deterministic relationship between technical change on the one hand and standardisation on the other. The other perspective highlights an evolutionary aspect of technical change and complexity as such, i.e. how technology progresses in time through an iterative process of continuous production of variation, subsequent selection and as an aggregation of selection through retention resulting in stable configurations.

The first perspective on standardisation foresight relates to the role standards can play as focal points of coordination and reduction of complexity and the relation between research and standardisation as such. As Gauch (2006) characterised, standards can constitute important phases in the generation and diffusion of new technologies, mostly by facilitating coordination across different communities that follow a similar paradigm.

Such different communities usually consist of actors that are embedded in different organisational contexts. This function of standards as boundary objects between communities, shifts attention to the technical and scientific issues that are addressed by standards and standardisation. According to this view content and success of standards are largely influenced not only by the standardisation body that produces these standards but also by the different actors involved. Gauch (2006) describes this fit between the realm of research and the realm of standardisation by three mechanisms: First, standards act as closure of technology; second, standardisation is a form of social closure in the process of technology generation; and third the integration of research into standardisation represents a special type of technology transfer.

Considering the first mechanism, standards act as a closure of technology with effects similar to those of technological trajectories (Dosi, 1982; Schmidt, 1998), in which the innovation tends to be oriented along the path of a trajectory (Nelson & Winter, 1977). Especially at the re-emergence of a new scientific discipline, highly dispersed language within and among fields is used. This holds true in particular, when the new field is developed from distinctly unconnected communities. In such cases a standardised terminology can reduce these fragmentations and bundle R&D activities and bring different communities together. That is, standardisation can act as a catalyst for further technology transfer expediting research activities or even, in later states promote trade or have other forms of beneficial economic effects (see also Swann (2000) or Blind (2004)).

The second and third mechanisms are strongly linked. To provide a guideline on successful standardisation it is necessary to answer the question how R&D and standardisation are related to one another and why the involvement of different research actors is an important factor of success for standardisation. On the one hand the involvement of different stakeholders alters the possible outcome of standardisation, i.e. they influence largely the content and quality of a standard they conduct. Hence it is impossible to predict the outcome of such standardisation processes by assessing the technical development or technological change. Still the willingness of scientist to participate and integrate their knowledge into standardisation is often rare. So, at least in most fields, scientists are often unaware of standardisation activities on the national, European or international level.[1]

These closure mechanisms have the potential to alter network configurations between different types of actors, with the concept introduced by Callon (1997) which links the state of networks to stabilisation in techno-scientific fields. Emergent and stable configurations are in Callon's (Callon, 1997) interpretation the polarised extreme states of networks, with a number of states between them. One challenge to standardisation foresight is therefore to identify emergent configurations that are part of a complex technical field. These emergent configurations are usually represented in thematic subfields that form distinct clusters but belong to a larger agglomeration, which comprises the complex technical field. Typically, members of such emergent configurations are affiliated to research laboratories, which can be both from academia and industry. Relevant knowledge created in such configurations is not fully covered by codified knowledge as a large extent of knowledge in such networks is implicit and is linked to the members of the networks, successful standardisation should include all researchers in the standardisation process, in terms of the inclusion of relevant knowledge (Gauch, 2006). From this perspective the role of researchers for standardisation is of high importance as the integration of their knowledge can improve the quality of standards as well as the long-term fit between the developed standards and the realm of research and development.[2] In addition, the involvement of all important research groups reduces the risk of developing different conflictive standards.

In the case of emerging technologies, featuring heterogeneous stakeholders increase the relevance of standardisation as well as the relevance for research integration with increasing complexity. The ideal type of a relationship between research and standardisation is in this case represented as an interaction of certain phases in the life cycle of innovation activities and standardisation activities. As Blind & Gauch (2009) derived: In early phases of the innovation cycle terminology and measurement and testing standards support the coordination of relevant

[1] A holistic approach to standardisation foresight can help to identify the relevant players using bibliometric methods. Still, this option is not in the focus of this paper. A more detailed discussion on how to use methods of standardisation foresight for stakeholder identification, is given in Blind & Goluchowicz (2008), Goluchowicz & Blind (2011a) and Goluchowicz & Blind (2011b).

[2] For more details on this see Gauch (2006).

communities of basic and applied research in their work with positive coordinative effects for later stages in the innovation process when research is turned into prototypes and products.

These types of standards relate to an increased potential to exchange knowledge between basic research on the one hand and applied research and experimental development on the other. Interface standards bypass the gap between applied research and experimental development and guarantee interoperability of integrated product components. Both interface and compatibility standards facilitate an improved transition from pilot products into mass markets by facilitating lower costs for the supply, production and distribution of products and services, to ensure the interoperability between products and, above all, quality standards which guarantee that the products comply with some minimum safety regulations (Blind & Gauch, 2009).

While the first perspective focuses more on the interaction of different research contexts such as the interaction between researchers from basic research and applied research the perspective of evolutionary and complex fields opens the perspective for an additional level of complexity by treating a complex emerging field as a conglomerate of distinct communities of practice that are organised into distinct subfields. In such a case it is therefore not sufficient to solely focus on distinct phases in the innovation process but rather take into account the distinct characteristics of the individual subfields. Three distinct phases can be distinguished: development, stabilisation and a mechanism of closure of technology variety and implementation (see also Weyer et al. (1997) and in a comparable way Glatzer (1998)).

Each phase can be described by certain key features that dominate it and results that promote further development. The phase of development is characterised by creativity and the generation of new concepts as well as stabilisation by linking strategies of heterogeneous actors, which is also characterised by increasing efficiency and a concentration on key issues. Interpreted in a way of closure processes, it leads to a reduction of uncertainty among the actors, as well as limiting the degrees for technical development. For a complex technology which consists of many partial technologies this is especially important. Then, in the phase of implementation and diffusion, networks, like networks of users, generated in the prior phase play a dominant role. In complex fields with multiple diverse types of actors the overall research field might as a whole be captured in a prolonged phase of potentially incommensurable and competitive patterns of selections by different communities. This could on the whole lead to distinct sub-disciplines that are unable to communicate, interact or exchange knowledge.

4.3 Research method

In the following we will specify a range of methods which focus on the handling of complex scientific areas instancing the field of nanotechnology and nanoscience, applying the discussed theoretical questions and considerations. The whole approach targets the identification of the underlying multi-layered structures and addresses this heterogeneity in the process of formal or informal standardisation. Three possible ways with different levels of detail to discover the underlying structure in complex emerging technologies using retrospective data are considered, namely historical outline through time series, cluster and network analysis as well as keyword analysis.

Considering the different possible methods for an explorative structure analysis of emerging technologies, the following reasoning is balanced. According to Compañó & Hullmann (2002), using a set of indicators like scientific articles and the number of patents is a reliable method to predict the potential of emerging technological fields. Scientific publications can be used as indicators for basic and applied research activities. Patents can be used as an indicator for development activities that occur at later stages in the innovation cycle.

Focusing on scientific publication, Lim (2000) found that on an institutional level, the correlation between the number of publications and patents in field for rapidly emerging technologies is high. Even though this suggests that patents can be a reliable source of information to predict changes in complex technical fields Robinson & Propp (2008) argue that in emerging technological fields the use of patent data is problematic, due to the disclosure period of 18 months before patent applications are published, the most recent dynamics in the technical field may not be captured adequately. Therefore, scientific publications are chosen to analyse the underlying pattern and indicators of the dynamic of emergence for new and emerging technologies.

To provide examples of how these methods can be applied in the context of standardisation foresight a field that represents both a high level of dynamics in the recent decade as well as a high level of complexity in terms of relevant scientific fields and diversity of actors was chosen. Even though the methods presented in this paper are not per se limited to complex emerging fields, the exploratory methods that aim at identifying topics provide the most benefit in the case of high complexity and uncertainty about future developments in a scientific and technical field. As an example for such complex emerging field, nanotechnology was chosen as it meets the following criteria.

Generally, emerging scientific fields can be characterised by a constant and continuous increase of both scientific publications as well as patent applications. For the field of nanotechnology and nanoscience this can be observed over the last two decades and according to Compañó & Hullmann (2002) and others, it is supposed to become one of the key enabling technologies of the 21st century. As van der Valk et al. reason, especially emerging technologies in high-technology and knowledge-based sectors, such as biotechnology and nanotechnology, are characterised by rapid development in terms of significance and development rates of new ideas and technologies. Here a gradually broadening range of scientific and technology fields are included, which keep changing as science and technology progress over time.

This diversity of application areas and involved research communities increases the complexity of the development of such technologies and has serious implications on standardisation and regulation processes regarding for example nomenclature, interoperability, consumer health, safety and environmental concerns. Specifically with the emergence of new science disciplines and an arising dynamic in the technology development often causes difficulties, because the different use of language and technical terms in diverse research communities can constitute not only communication problems but also hamper the identification of similar exploratory focus and cooperation potentials as well as community-comprehensive research and development. Hence the identification and approach of all necessary topic-sharing science communities and the creation of a uniform nomenclature and setting standards at an early stage are important factors that provide some reduction of complexity, e.g. through similar wording.

The next subsections discuss the analytical proceeding with the help of a search string generated dataset of 184.901 scientific articles generated from the Science Citation Index (SCI), one of the more important databases about scientific publications (Bengisu & Nekhili, 2006) addressing the subject of nanotechnology ranging from 1975 to 2008.

4.3.1 Historical outline

The most straightforward way of capturing the evolution of a scientific field is to take a look at aggregate changes in the field as a whole by decomposing the overall trend into smaller thematic subfields that can then be monitored both in terms of their relative importance and changes in overlapping between such fields. This approach, even though rather simple from a methodological point of view, provides a good starting point for further advanced analyses and can also provide initial clues on the overall changes and the level of complexity in a field. Some fields like mechanical engineering, where, thinking along the lines of Callon (1997), the scientific-technical network structures have attained a certain level of maturity and even stability, only little sub-thematic evolution can be observed over time. In more fluid fields like nanotechnology however, multiple shifts in importance of certain subfields occur in relatively short time frames.

The challenge here is to extract patterns from these evolutionary changes at the field level that in later steps can be used as a starting point for identification of topics as well as relevant stakeholders from the realm of research.

Starting with such a general qualitative analysis of the historical outline of the technology field on an aggregate level, the first scientific publications referring to the subject of nanotechnology from 1975 to 1990 was surveyed. In the following the development of the different communities for the time period from 1991 to 2008 with quantitative methods was analysed.

Based on the publications between 1975 and 1987 of the downloaded dataset at hand the scientific field of nanotechnology has its origin in the medical field, namely molecular biology, biochemistry, cell biology, pharmacology and medical chemistry. Until 1990 mostly topics concerning drug development, drug delivery and targeting, nano-capsules, cancer research, toxicity, cell labelling, biotechnology, ceramic nano-materials were mostly published. With a short time lag the scientific communities of applied physics, metallurgy, polymer science, spectroscopy, condensed mater physics, electrical and electronic engineering and mechanics also address this field in a more basic way. Here the topics until 1990 were nanostructures in general, the characterisation of nano-particles, particle sizes and surface analysis, nanostructure fabrication, nano-crystalline structures, nanolithography, first developments of nano-composites, thin-films, electro-conductive nano-crystalline silicone, nano-electronics, quantum dots and diodes.

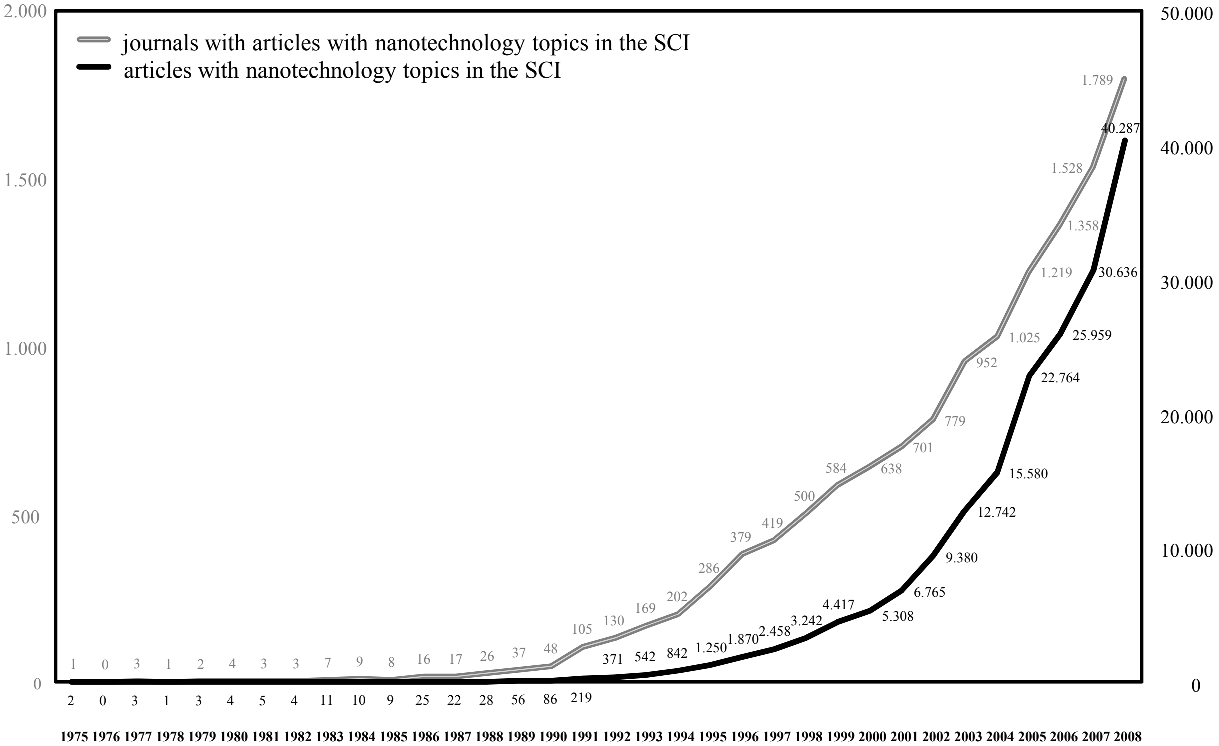
After 1990 the dataset reveals the dynamic development in the whole field. Until today, the number of scientific publications in several areas of application, has increased including fictionalisation and refinement of surfaces, material science, optics, conversion and usage of energy (e.g. solar and fuel cells), electronics, sensory, data processing and transfer, telecommunications, microscopy, chemistry, diagnostic and therapeutic agents, biocompatible implants, nanobiotechnology or cosmetics (see also Blind & Gauch (2009)). To explain this further, figures 4.1 and 4.2 show an integrated illustration of the development on the number of scientific articles and the corresponding number of journals as well as the corresponding numbers of involved communities represented by the subject categories downloaded from the SCI with topics in nanotechnology.

Similar considerations on the characterisation of scientific publications and patent applications can be found in Heinze (2006) and Heinze (2004) as well as in Compañó & Hullmann (2002).

This first approach covers only the observable dynamic in the occurrences of the published articles. But to identify and track the underlying structural interdependencies it lacks an analysis of the network structures of the sub domains and its change and developments. Though as an implication for the identification of required standardisation activities, it can act as a first indicator for the development and can display the complexity by counting the number of involved science communities.

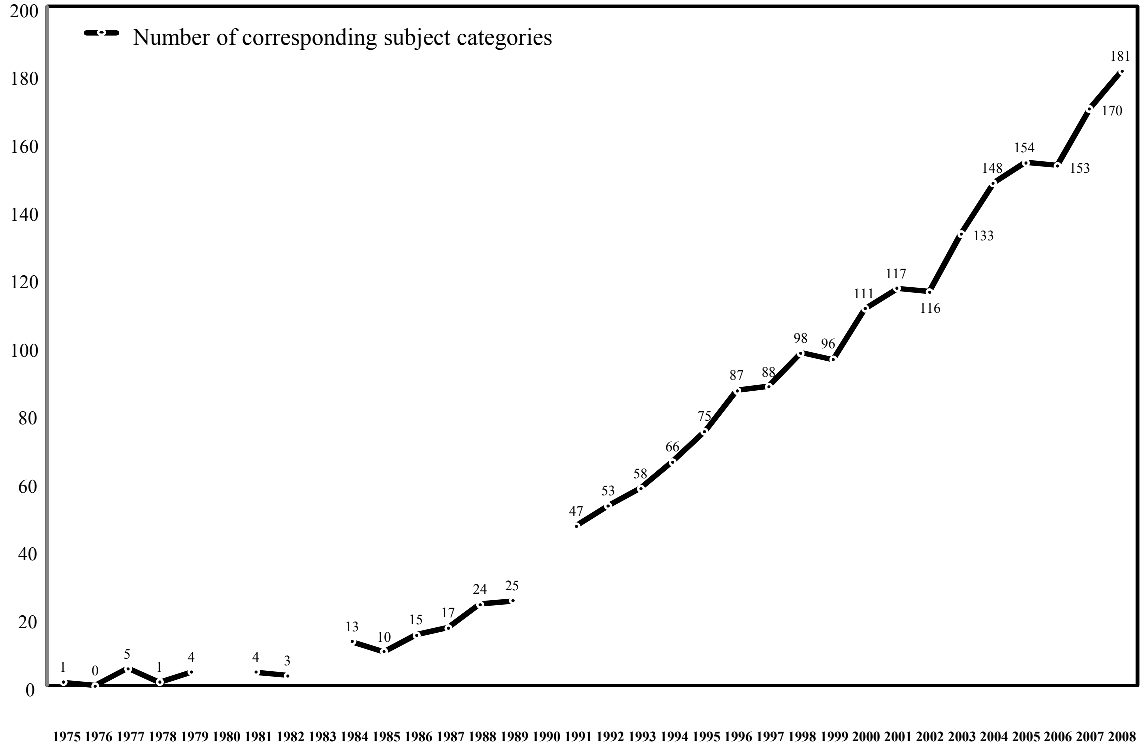
Even though historical timelines can provide some interesting and valuable results, they do not capture the level of complexity in fast evolving heterogeneous fields. That is one shortcoming that has already been addressed and is rather related to the interaction between fields than to the changes of relevance of certain fields over time that can be captured by a simple time-series. While a historic timeline can only cover simple trends for one field, most of the complexity will occur between the fields, i.e. in the overlapping regions between fields.

Figure 4.1: Number of identified articles and the number of corresponding journals in the SCI from 1975 to 2008 addressing the topic of nanotechnology.



4 Supporting Successful Standardisation Processes in Complex Emerging Fields through Quantitative Analysis – The Case of Nanotechnology

Figure 4.2: Corresponding number of subject categories in the SCI from 1975 to 2008 addressing the topic of nanotechnology.



4.3.2 Cluster and network analysis

To account for complexity, advanced approaches from cluster and network analysis that take into account both the evolutionary character of the developing emerging technology fields as well as the overall dynamics are used. In it, the development of the co-classification of the subject categories in the Sciente Citation Index (SCI) in the field of nanotechnology on the composition and its stability over time with cluster and network analysis for subsequent time periods is tested. For this analysis six three-year periods of publication data extracted from the SCI covering a timeframe of 1991–1993 to 2006–2008 are used.

The data for each period is processed by hierarchical clustering methods using Ward linkage and Pearson correlation[3] as a similarity metric for the subject categories as well as more advanced hierarchical clustering methods using p-values to account for uncertainty in the clustering algorithms.[4] The p-values are calculated via multiscale bootstrap resampling.[5] For each of the cluster p-values can be calculated a range between 0 and 1 indicating how strongly the cluster is supported by the data. Figures 4.3 and 4.4 show an example cluster analysis using p-values based

[3]Complementary definitions can be found in the annex.
[4]I.e. the p-values measure the accuracy of the clusters.
[5]For further technical details consult the R package description by Shimodaira (2004a) as well as Shimodaira (2004b).

on this method for the period of 1991 to 1993. According to this method several time slices were investigated. Based on this method we can disaggregate the data into 17 to 47 clusters for the different time periods.

In addition to the cluster analyses the co-classification of the different time periods is related to one another and is described as a network. Here subject categories represent the nodes; the co-classifications were represented by the edges of the network. As a result six networks which relate the subject categories according to their co-classifications were obtained. A graph-based network visualisation of data transformed by using the widely used Jaccard index for the dataset for 1991–1993 and 2006–2008 is provided in figures 4.5 and 4.6.

The Jaccard index maps the co-classifications as distances in space and the diameter of the nodes represent betweenness measure for the subject categories indicating the degree of the interconnections.

Like the time series in the first approach, both analyses capture the dynamics of technical change. Comparing the associated results, figures 4.7 and 4.8 show 17 and 47 identified cluster for 1991–1993 and 2006–2008, respectively.

Based on the analyses of the cluster and the network approach, stable configurations can be identified. In the case of nanotechnology, some clusters get stable over time. These clusters comprise Mineralogy, Metallurgy & Metallurgical Engineering and Mining & Mineral Processing as well as the clusters around Materials Science; Coatings and Films, Applied Physics and Condensed Matter Physics.

Both approaches used so far provide a good starting point as they can provide standardisation organisations with enough information to identify the general trends in a complex field. In some cases the information gathered in the first two steps might be sufficient to develop overall long-term strategies, like the formation of new technical committees or thematic subgroups in larger technical committees. In some cases it even might be sufficient for stakeholder identification, as it will help to identify researchers or research institutions by using simple publication counts either in the different single fields that have gained much importance or in overlapping patterns of fields that become more prominent over time. These methods will generally provide good results for fields that already feature a certain level of stabilisation, i.e. a reduction in measures of density (e.g. Shannon Entropy or Herfindahl Indices applied the subfield structures analogously to the approaches by Blind & Gauch (2008)).

There is one caveat though that relates to new fields and to the relevance of different types of standards at different stages in the interaction between research and standardisation. As already discussed in the introduction, the first aspects that require standardisation will, in most cases at least, relate to terminology. In this respect nanotechnology is a prominent example of this. The challenges in such processes that relate to terminology standardisation are at least threefold relative to our approach.

First, terminology standardisation is heavily based on the tacit input of researchers that are currently developing new concepts, approaches and research questions, which may also become relevant for the market at later times. This aspect becomes even more important when the dynamics of a field are very high. Second, in cases where a field is complex, i.e. there is high heterogeneity through fragmentation into different subfields; this heterogeneity has to be taken into account. Ignoring this heterogeneity may hold dire consequences for standardisation activities, at least in the long run, their results becoming obsolete or not achieving the beneficial economic effects. Finally, this heterogeneity in the use of language may not be apparent when focusing on thematic fields or interaction of thematic fields as units of analysis. To achieve a more detailed understanding, the level of abstraction has to be refined even more to provide valuable insights.

Figure 4.3: Hierarchical clustering of the subject categories of the found nanotechnology articles in the SCI for the time period 1991–1993 (clustering method: Ward linkage; similarity measure: Pearson correlation).

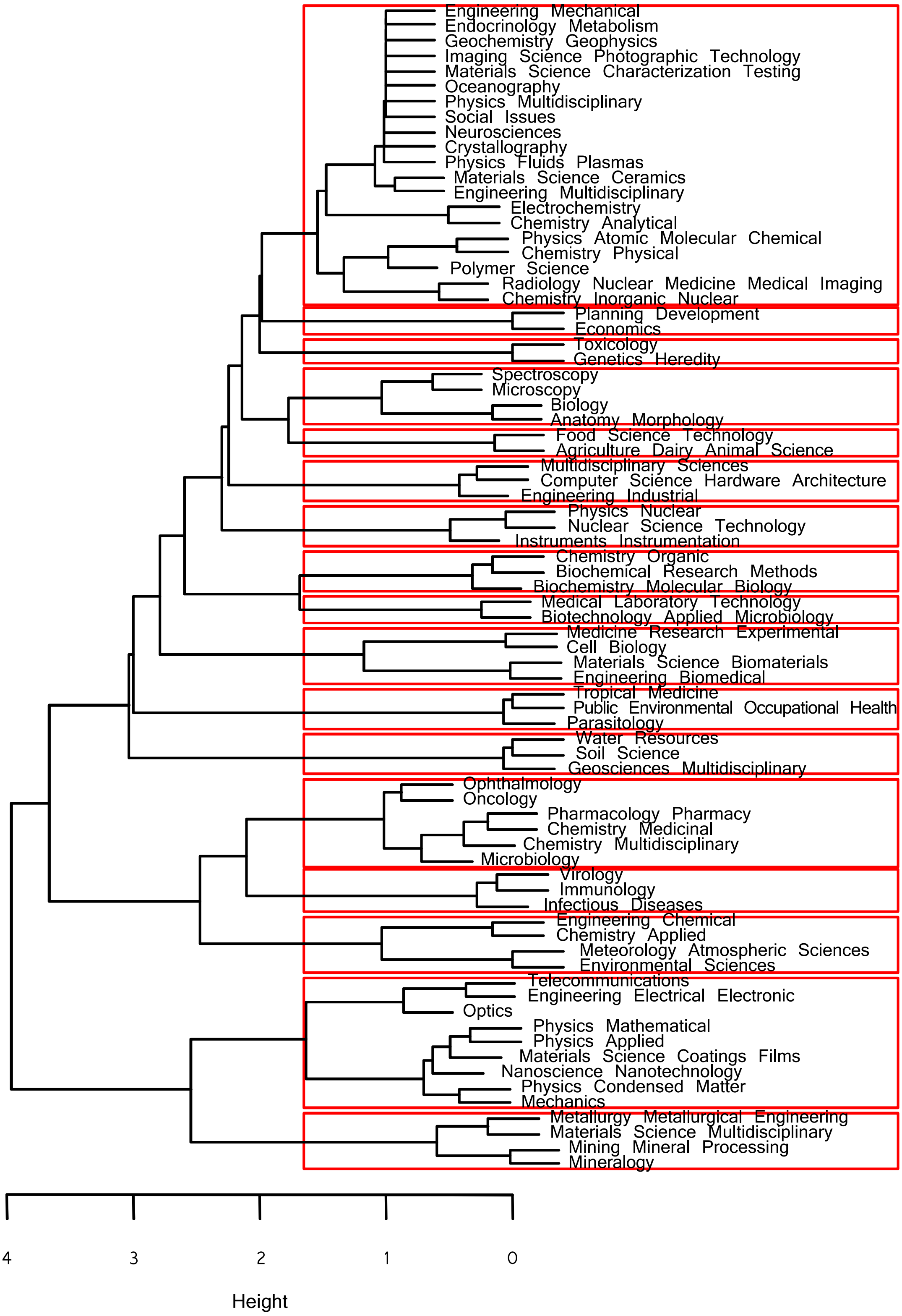


Figure 4.4: Hierarchical clustering with p-values of the subject categories of the found nanotechnology articles in the SCI for the time period from 1991–1993.

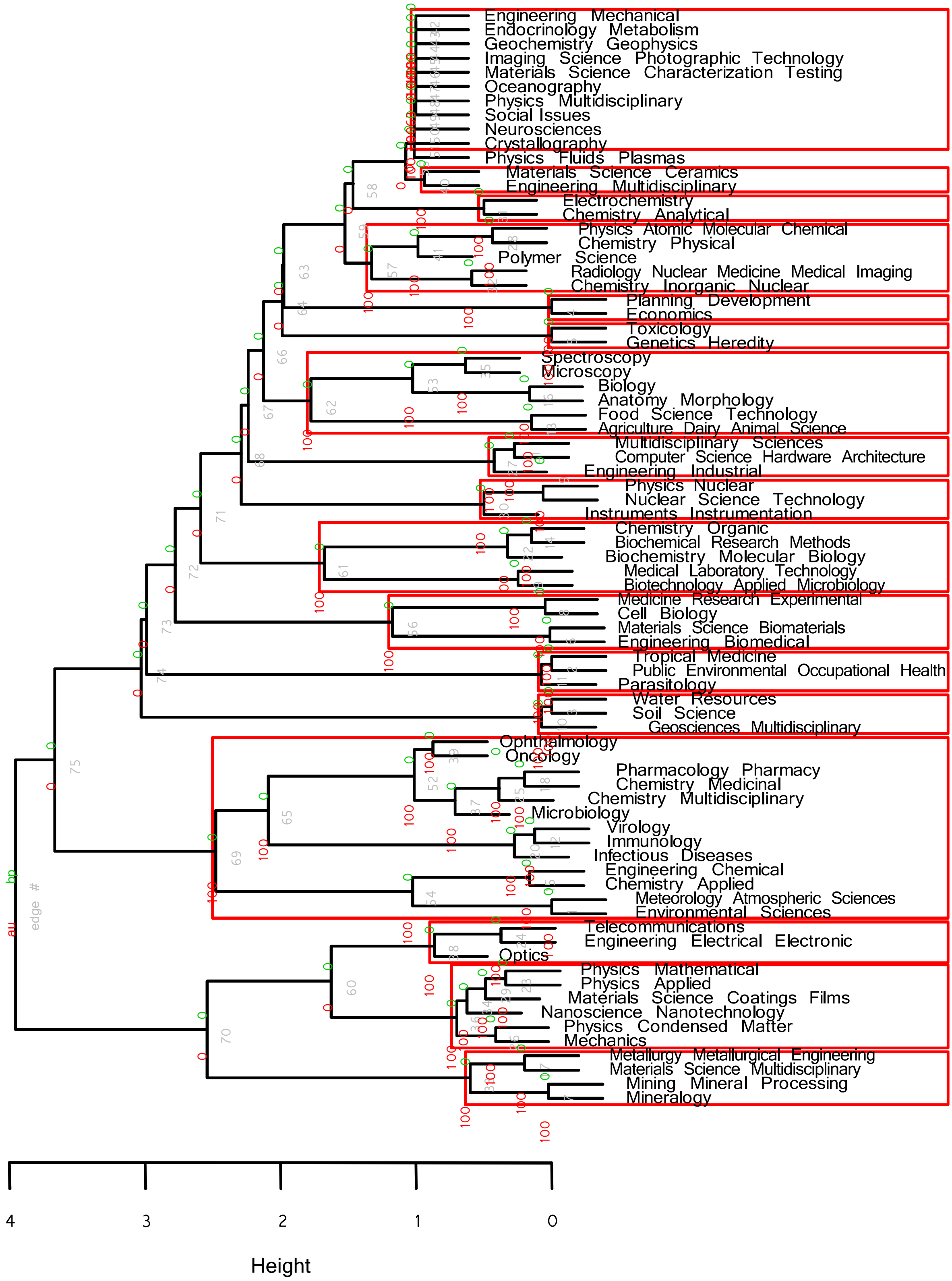


Figure 4.5: Co-classification networks of subject categories of the found nanotechnology articles in the SCI for the time slice 1991–1993 (Jaccard index > 0.1).

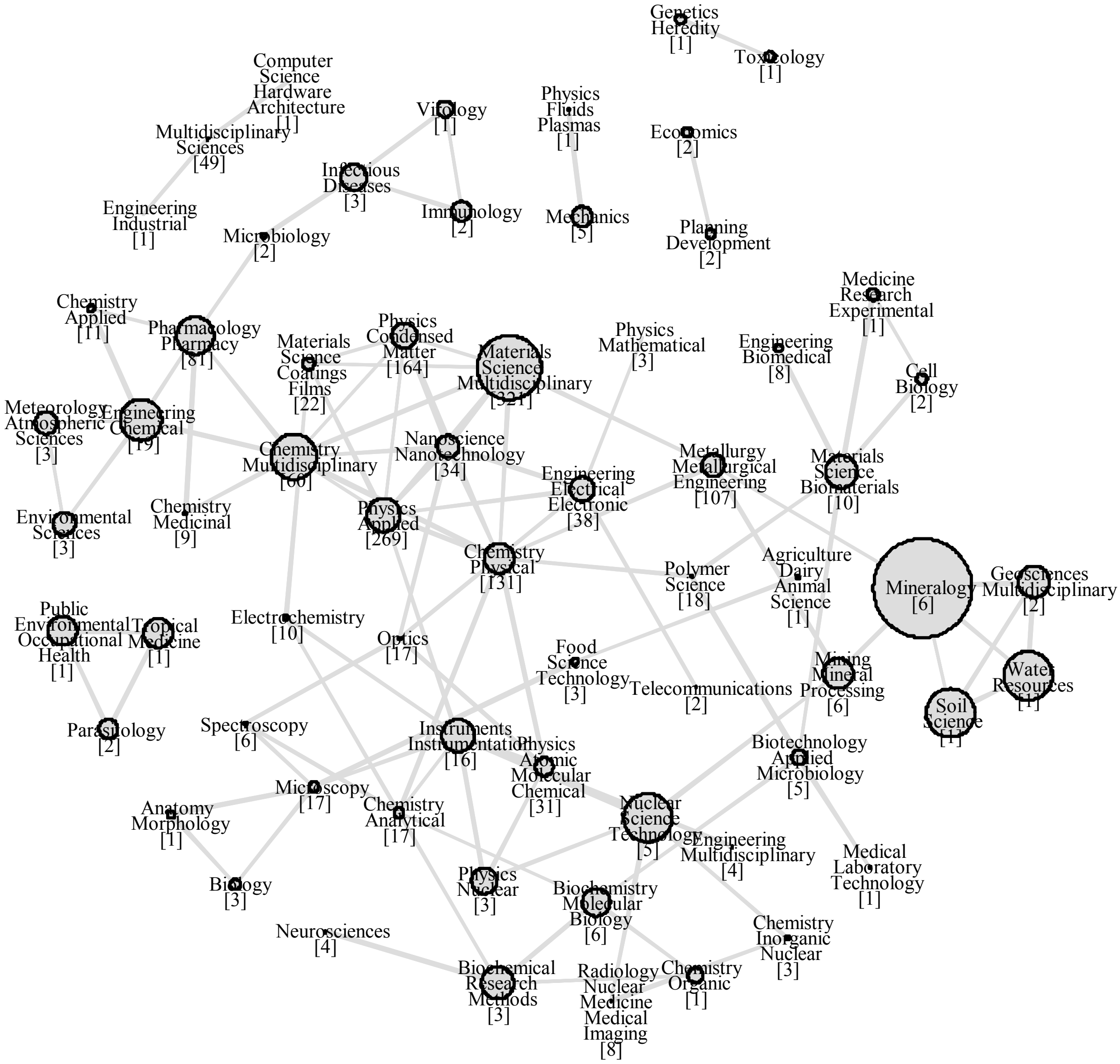


Figure 4.6: Co-classification networks of subject categories of the found nanotechnology articles in the SCI for the time slice 2006–2008 (Jaccard index > 0.1).

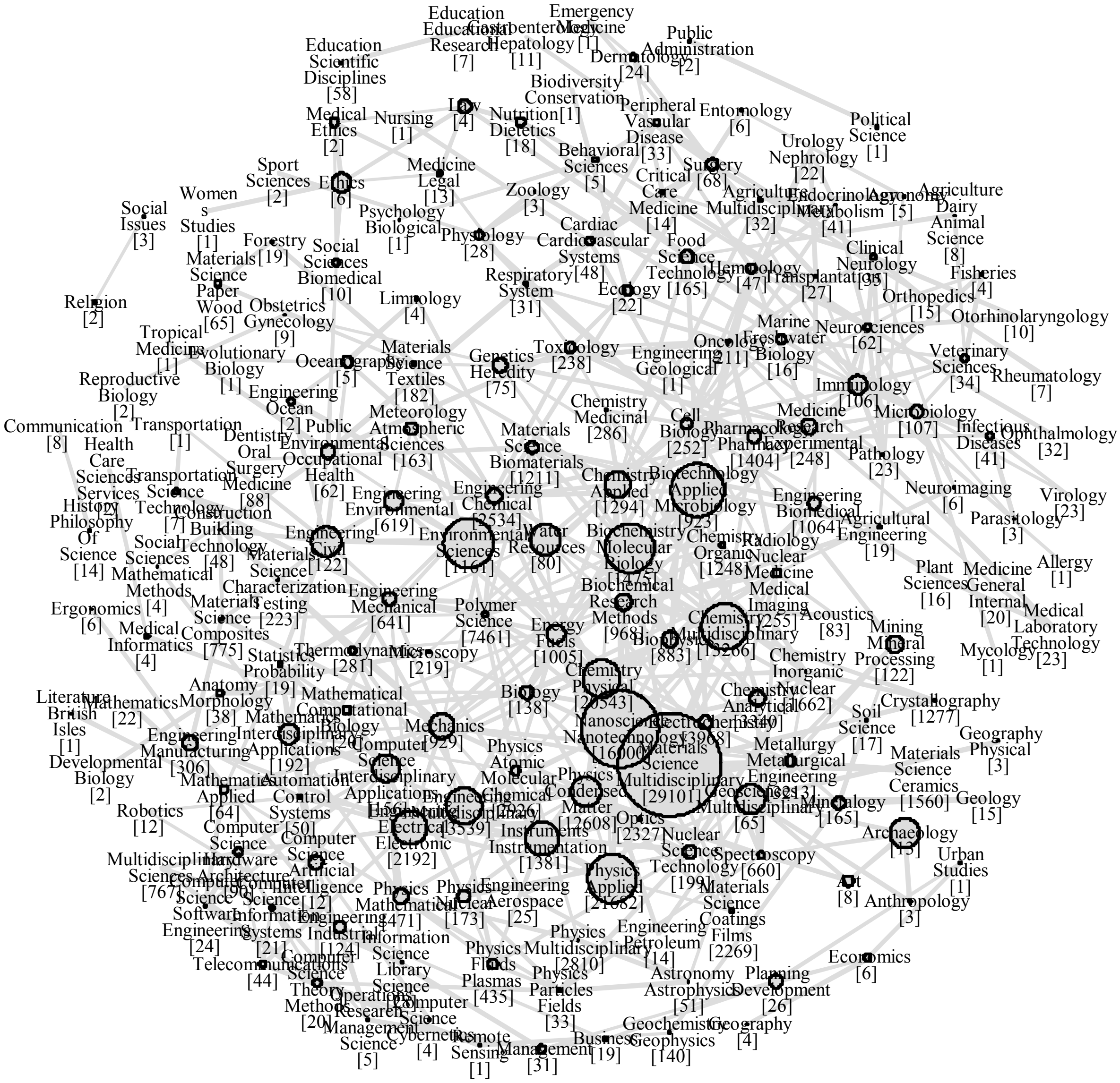


Figure 4.7: Hierarchical cluster analysis of then subject categories of the found nanotechnology articles in the SCI for the time period 1991–1993.

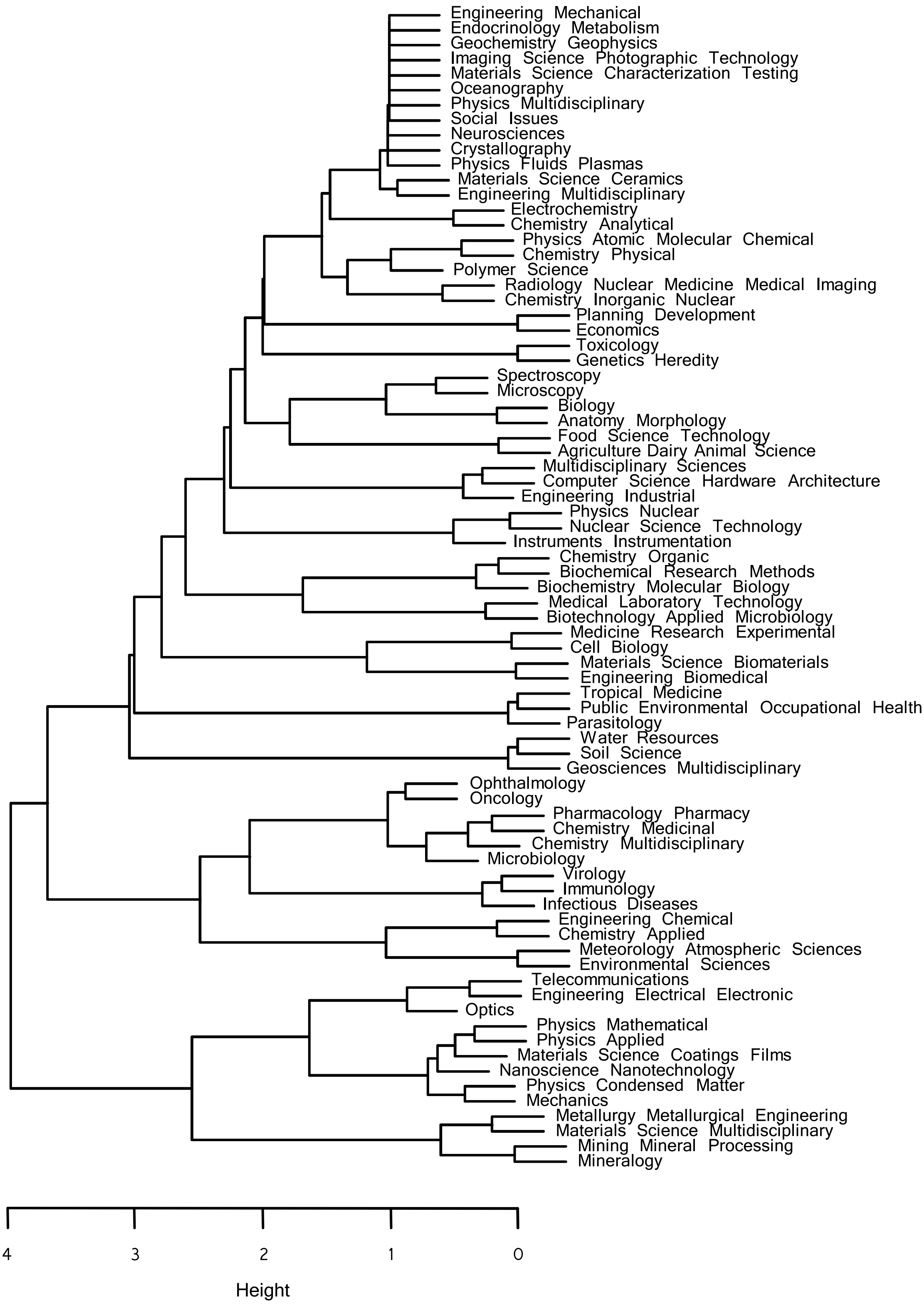


Figure 4.8: Hierarchical cluster analysis of then subject categories of the found nanotechnology articles in the SCI for the time period 2006–2008.

4.3.3 Keyword analysis

To provide a further in-depth analysis of the participating communities on a third level of detail, the changes and development of author keywords in the articles is examined, to obtain explicit information about the connections and interactions between the research areas and their topic foci at this way. As described in the introduction, the different uses of language and technical terms in diverse research communities and application areas have serious implications on standardisation processes and cause difficulties especially for setting terminology. On this issue the assignment of keyword analyses can highlight diverse use of wording and content.

As above, the dynamic of the field development is mirrored in the increase of the number of obtained author keywords for the different time periods. To illustrate the proceedings of this approach one part of the analysis for the time slice 1991–1993 is presented. At this juncture the approximated 800 keywords of the 1,132 articles were matched to the calculated 17 clusters of subject categories to get these keywords which were used in more than one community. In addition, a co-word analysis was carried out and these keywords and their interconnections then were depicted in a keyword network (see figures 4.9 and 4.10).

The analysis showed disjunctive use of keywords amongst physical and material domains on the one hand and mainly medical domains on the other hand. Here NANOCRYSTALLINE, SOL GEL and NANOSTRUCTURE unite the physical topics, but there also exist connections between the communities through keywords like NANOPARTICLE, ALUMINUM, NANOLITHOGRAPHY, IN-SITU, SILICON, LITHOGRAPHY and ATOMIC FORCE MICROSCOPY.

Similar to our approach, Calero et al. (2006) presents a method to identify research groups using also publication analysis and measures their collaboration in the field of nanotechnology. They analysed co-authorship data from 1996 to 2003 and applied bibliometric mapping techniques and network analysis to identify and classify different research groups. To cover the underlying keyword trends of the knowledge process, they generated as a result a bibliometric map of nanotechnology and identified research groups based on their similar research activity. Also Ding et al. (2001) uses co-word analysis to pinpoint the pattern and trends in a specific science and technology field by analysing author keywords and phrases from the title and the abstract of the articles. For the interested reader, they also provide a description of the different methods and software for the implementation of co-word mapping. Small (2006) provides a co-citation cluster mapping method for tracking and growth prediction in science areas and the associated researchers in these areas. Similarly, the paper gives an overview of the different methods for the analysis of research areas like histographs, co-citation analysis of documents or authors, co-word analysis and journal mapping.

In combination with the different methods described above, this third approach provides not only the analysis of the outlined research topics and information about the required areas for standardisation activities and need for discussions, but it also holds the possibility to identify the different communities and beyond this the identification of relevant players who can speak for the community.

Figure 4.9: Histogram of the article related keywords of the found nanotechnology articles in the SCI.

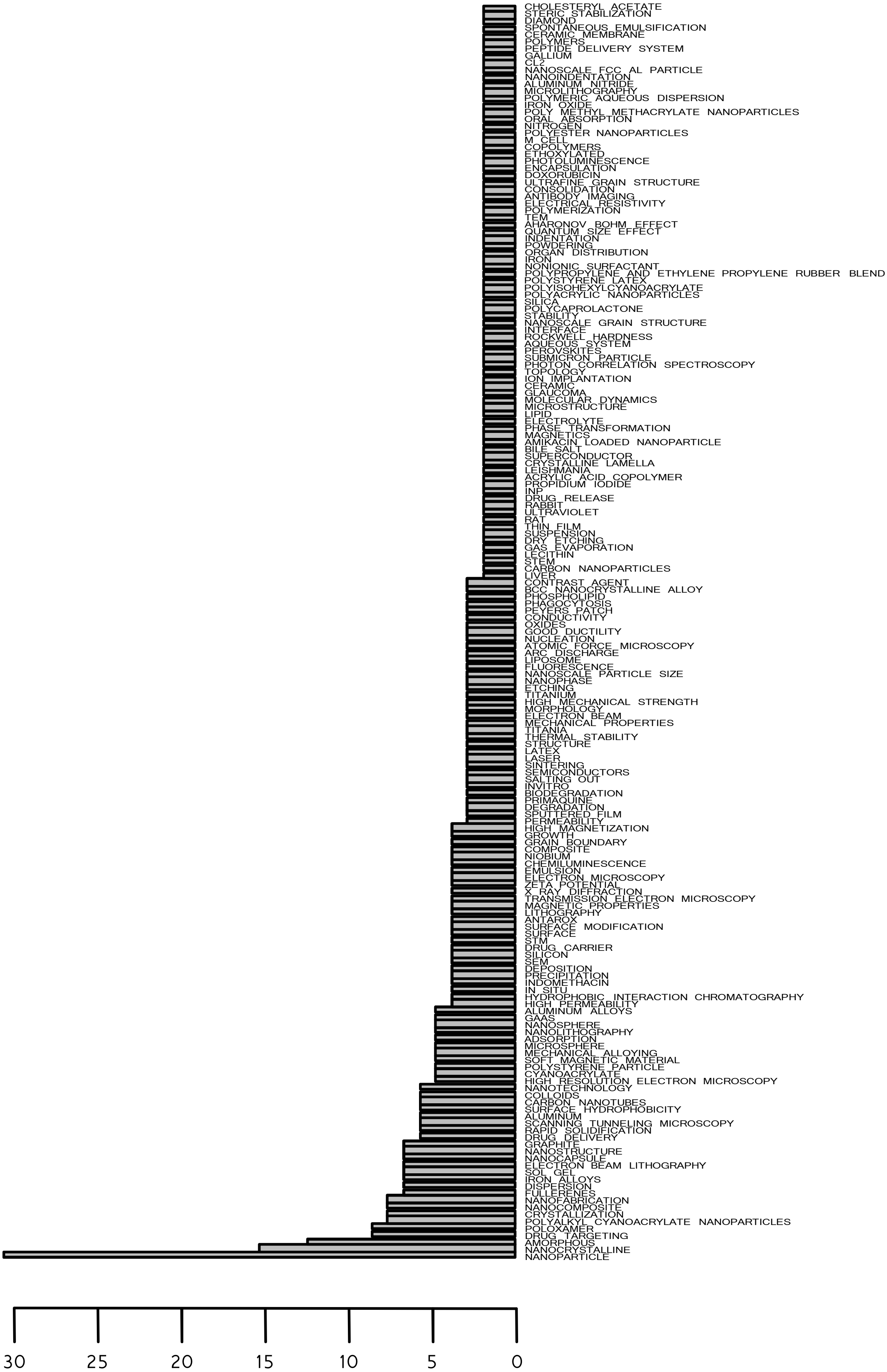
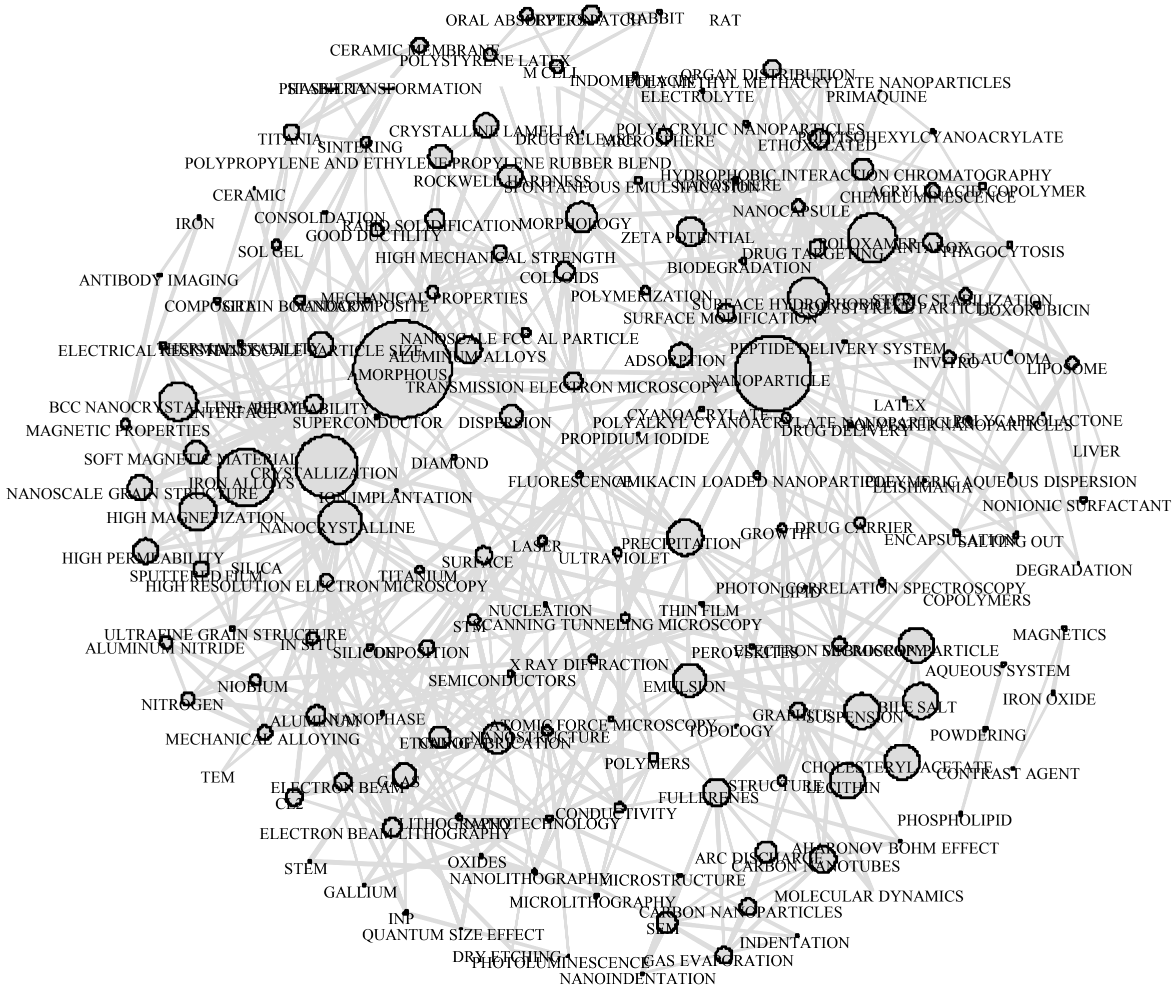


Figure 4.10: Corresponding co-word network of the article related keywords of the found nanotechnology articles in the SCI (Jaccard index > 0.1).



4.4 Implications for standardisation foresight

In the following, a short overview of how the results of such approaches can be used in the context of standardisation foresight will be provided. To provide a practical perspective on these methods, the actual results based on the analysis of the field of nanotechnology will be used.

While simple historic time-series are comparably cost-effective to construct as soon as the data like publications, patents, trademarks etc. are available, more advanced methods, if conducted correctly by professionals that might not be at the disposal of standardisation organisations, require more resources but will reveal more in-depth structures that cannot be discerned by simple time-series.

Approaches from cluster analysis or network analysis using data that is organised into subfields hereby uncover structures of interdependency among these fields. Giving up this subfield structure and relating to semi structured natural language data from abstracts, titles or full text passages can reveal even more granular knowledge. The trade-off in this case is that the results of these analyses might lack an overall context that is needed to identify relevant larger groups of people or the large scale trends that are responsible for the evolutionary dynamics of a complex field. This trade-off between granularity and context can best be addressed by using a mix of methods that relate to different levels of abstraction to form an overall picture that can aid standardisation organisations in multiple ways.

The first two methods, i.e. historical timelines and interdependency of fields can help standardisation organisations establish structures like technical committees, sub groups and strategies. Such structures will help attract the highly specialised researchers from the thematic subfields and those that are conducting research at the borders and overlaps of these subfields. Establishing these structures already provides a high benefit and will also help signal their readiness and relevance to the field. A standardisation organisation that is not structured according to such agglomerations of topics might be poorly prepared to absorb knowledge from the field. In the worst case this might even lead to conflicts about the 'hot topics' of a field. Historical timelines can also help standardisation organisations and can be viewed as a signal.

Especially the shift towards electronics and electrical engineering can and indeed has caused frictions in standardisation. As in some countries on the European and even on the international level, both electrical engineering and electronics are addressed in separate institutions than the more general standardisation topics. On the European level, general standardisation work is addressed by the European Committee for standardisation (CEN) while electro-technical aspects are addressed by European Committee for Electro-technical standardisation (CENELEC). Analogously, on the international level general topics are addressed by the International Organisation for standardisation (ISO) and electro-technical aspects by the International Electro-technical Commission (IEC). Early identification of such trends ex-ante could help establish cross-cutting structures and ameliorate organisational frictions much earlier than solving such problems of responsibility when the topics become relevant from a point of view of industry or policy.

General topics in this early period are mostly towards nanostructures, characterisation of nano-particles and particle sizes as well as surface analysis, nano-composites and electro-conductive nano-crystalline silicone. Especially the first two issues that relate to description and measurement issues were first addressed as late as the early 2000s – a full decade after these structures could be clearly observed through analysis. These exact and basic topics also took considerable effort in standardisation work, partly because there was high heterogeneity in the different sub-fields towards these issues. The first standards in this respect were produced as late as 2008. Indicator based approaches would have been able to uncover such structures as early as 1995 through simple statistical analysis of readily available data that could have been obtained by lower cost compared to the negative overall economic effects of delayed standardisation.

In fields where the number of publications or patents increases exponentially, the chance that standardisation may become a beneficial methods for coordination increases.

Still, while these methods are helpful for establishing structures and shaping the framing conditions of standardisation work, they will usually not be the best choice for identifying more concrete topics and in cases standardisation work starts mostly at square one. In such a case especially when terminology, usually the first topic to be addressed, is involved, more in-depth approaches are needed to identify structures that are underlying the subfield structures. Such language constructs like jargons or the terminology itself can be highly dispersed both within and among fields. This complex structure that represents an interconnection between language use and physical artefacts can have severe consequences when products are later introduced to the market.

Using the initially discussed mechanism of technological closure we look for structures that can be found through the analysis of keywords which are used to identify both interesting constellations of co-occurrence of technical terms as well as the stakeholders using these terms. This opens up opportunities for standardisation organisations to play an active role that includes inviting relevant experts that might usually be unaware of standardisation activities. This in turn will strengthen the relevance of the final standards in the field as they better reflect the overall situation in a field. Aside from the direct benefit to terminology standardisation, these methods can also be used to discern more technical topics. Still, in such cases standardisation organisations should use complementary methods like surveys or modified Delphi methods where the relevance of standardisation of the identified topics can be evaluated (see Goluchowicz & Blind (2011a), Goluchowicz & Blind (2011b) and Blind & Goluchowicz (2008)). In such cases these methods bear a twofold benefit both as a source of potential standardisation topics and as a source of relevant stakeholder to address in the surveys.

Even though this method can universally be applied to complex emerging fields, the meta-field nanotechnology shows how these methods can provide insight on different levels. First, it can provide context through trends. The shifting nature of the use of nanotechnology is directly apparent in the historical timeline. These general trends represent a shift in the early 1990s from a more medical focus of nanotechnology shifted towards physics and material science and at later stages towards electronics. These shifts do not necessarily reflect a paradigmatic shift in nanotechnology as such but rather a shift towards nanotechnology in different fields.

4.5 Conclusion

This paper attempted to provide standardisation organisations as well as academics and practitioners in the field of standardisation research with a methodological blueprint to conduct indicator-based approaches that can help to identify trends, topics and relevant actors in emerging technologies that are characterised by both rapid development and complex constellations of different research fields that interdependently construct this field as a whole. For the concluding evaluation of the proposed methods, the advantages and disadvantages of each method are compared (see table 4.1).

Table 4.1: Comparison of the chosen approaches.

Method	Advantage	Disadvantage
Historical Outline and Time Series	• good measure of overall dynamics of a field • low requirements to data granularity • cost-effective approach	• fails to account for complexity
Cluster and Network Analysis	• suitable method to identify structures of a complex field • suitable method to account for stability and change over time	• may require aggregation of data into longer periods, does not account for complexity that is not captured by the classification scheme employed
Keyword Analysis	• shows the functional and thematic differentiation as well as the shifting of foci over time independent of classification schemes	• surplus of information and information overload, linguistic problems may arise (homonymy, polysemy, synonymy, etc.) strong requirements to data (fulltext data)

Even though the choice of methods was indented to reflect increasing levels of complexity and depth of focus, they were also ordered in terms of increasing cost of analysis and time consumption. Thus the upper level approach holds a schematic perspective of the increasing activities in a field. But it fails to indicate the underlying complexity and complex interrelations. The cluster and network analysis on the next layer offer the identification of different subgroups of communities and scientists and its structures. But if this specific kind of complexity were overrated, others will be missed out. Thus the approach on the lower level shows in full detail the functional and thematic differentiation as well as the shifting of the foci over time. But the high differentiation comes with the risk of surplus of information. Furthermore the topic and keyword evolution is subject of major fluctuations the results are less stable than the development on the level of the field. Hence all three methods should be viewed as a package to classify the information correctly and set them into the right context.

In some cases it is suitable to install monitoring only at the first level of abstraction at first, i.e. by historical timelines. This can already help make informed judgements on future resources or strategic decisions on a structural level. Only in cases where there is an above average increase in output from the scientific-technical community, standardisation organisation should address the more complex task of analysing interdependency structures for those selected fields.

Methods from cluster or network analyses can then in a next step help to refine strategies towards topics that relate to multiple technical committees in a standardisation organisation. In cases where stable patterns of interdependency arise, they can use keyword approaches as well as complementary methods like expert consultation and surveys in the scientific-technical communities identified as a result of the historical timelines and the cluster and network analyses. The keyword approaches, due to their cost-intensive nature and high level of expertise required for proper analysis should only be used in cases where both the historical timeline analyses and the cluster and network analyses point towards critical mass. The benefits of keyword approaches are mostly on the level of generating a better idea of language use and topics in early stages that can help to identify communities and topics that are mostly relevant to terminology standardisation, but can also help to identify topics that will in later stages become more relevant like measurement and testing or quality and safety aspects.

There is also a pragmatic reason for applying these approaches in a sequence. The methods were deliberately arranged in a sequence that requires larger data sets that usually can only be acquired by using longer time periods to yield statistically sound results. While the requirements for historical timelines and trend analysis are comparably low, especially the keyword based approaches require a substantial effort of cleaning and amount of raw data. This is due to the diversity of language per se. Finally, it is advised that standardisation organisations either install a group dedicated to monitoring or seek external advice to conduct the more complex methods.

Appendix

Complementary definitions:

The linkage function specifies the distance between two clusters. Ward's linkage method seeks to choose the successive clustering steps so as to minimise the increase in error sum of squares at each step. The initial cluster distances are defined to be the squared Euclidean distance between points:

$$d_{ij} = d(\{X_i\}, \{X_j\}) = \|X_i - X_j\|^2. \tag{4.1}$$

Pearson correlation is defined by:

$$\rho_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y}. \tag{4.2}$$

The Jaccard index is a measure for comparing the similarity and diversity of sample sets. It is defined by:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}. \tag{4.3}$$

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5 Review on Five Years in Standardisation in the Field of Nanotechnology

Abstract

The strength and goal of foresight approaches is not an exact prediction or extrapolation from present to future states. It is rather an anticipation of future states that take the effects of interaction between stakeholders as well as changes in the overall framework of technical change into account. Evaluations based on predictive accuracy of such approaches potentially lead to fallacious quality assessments, as predictive accuracy can be the result of "correct" predictions of the foresight method or as well be the result of self-fulfilling prophecies through the orientation of stakeholders actively shaping technical change. The lack of counter-factuals makes decomposing the effects of both factors largely impossible. An assessment of the predictive quality of a foresight exercise can only be useful, to provide information on the plausibility of a foresight framework, and test if expected future states found in a foresight are antithetic to realised future states. In this article a qualitative assessment of a standardisation foresight approach in the field of nanotechnology is presented. Based on data collected in 2006, the results of a systematic foresight approach are being compared to the current status of standardisation activities in the field of nanotechnology. The general pattern of realised standards follows the evaluation derived from the foresight exercise performed in 2006.

In contrast to the expectations in the foresight exercise, in the beginning terminology standards are under-represented while measurement and testing standards have been developed earlier. The results of this assessment show that models aiming at a phase-oriented description of the relationship between the state of a research field and standardisation activities can not fully predict the outcome of standardisation. Rather technology-specific characteristics can be more appropriate than a function-oriented phase model such as the one developed by Blind & Gauch (2009) as already discussed in Gauch (2011) for the case of ICT. The fact that in emerging fields, standardisation activities might deviate from an optimal function-oriented model, provides an argumentative basis for a closer integration of standardisation foresight results into standardisation processes. From this perspective, a stronger integration of both, standardisation topics and stakeholders identified through standardisation foresight, complementing the self-organised approaches of technical committees, should strengthen the link between R&D and standardisation.

Keywords

Standardisation foresight, technology foresight, science and technology indicators, Delphi, impact analysis

Contents

5.1 Discussion and implications for future standardisation foresight

To assess the implementation of the objectives of the foresight approach and to assess its extensibility and adaptability in the following paragraphs, readers are referred to some tests[1] in the context to general foresight evaluation, established by Cuhls & Georghiou (2004): (1) Accountability, referring to questions of efficiency; (2) a justification, whether the effects of foresight legitimise its continuation and extension; and (3) learning, referring to further possibilities for improvements of the approach implemented.

The described approach was implemented in a foresight process during the period 2006 to 2009. A variety of topics could be identified, but for a total of 10 subjects in-depth analyses to identify future standardisation issues have been carried out. In order to identify general impacts and factors for success of the chosen foresight approach, an externally conducted evaluation[2] of the parent funding program was prompted. Here, various aspects of the whole program and the standardisation foresight approach were highlighted. The interviewees of the evaluation[3] rated the use of the standardisation foresight process extremely positive: 80% of the interviewed project managers in the German SSO would make use of the results based on continuous foresight process. 33% of the respondents have already adopted new technology fields for standardisation processes, identified by the foresight exercice. Also, the overall impact and the level of awareness of the approach is largely satisfactory. Nevertheless, the implementation of the identified issues holds further potential for improvement. This will be further discussed in the text below.

More specifically, the indicator part highlights national priorities in R&D activities through the choice of analyses, contributing to objectives (1) to (3). The chosen indicator approach in step (1) is quite appropriate for reflecting these objectives. Furthermore, the possibility for choosing different indicators and analyses methods makes it flexible for different focal points for the standardisation issue (e.g. search of scientific or policy driven fields).

Step 2 offers a variety of options to identify and target new players and actors for standardisation processes, which were so far only used for the implementation of the Delphi surveys. The analyses of all conducted Delphi surveys showed that an average of 31% of the participants were previously not involved in standardisation. Although new stakeholders were involved in the assessment of the standardisation issues in the Delphi survey, the approach, ends at this point. The new stakeholders were not actively included in the processing of the topics in the standardisation

[1] Especially number (2) and (3).
[2] Results from a study commissioned by the federal ministry of economics and technology (BMWi).
[3] Unfortunately, the exact number of the population of this study is not known.

committees. Due to monetary barriers and information deficits for new actors in standardisation, in theory this factor is discussed under the concept of social closure problems (see Schmidt (1998)). This can result in negative effects for the economic development especially when it comes to the development of new technologies. The active involvement of the identified stakeholders in the standardisation process or workshops to connect the surveyed experts could fill this gap and is a possible way to supplement the approach at this point.

Referring to the results of the externally conducted evaluation analysis, the observations of the recent years have shown that an on-going systematic collection of standardisation issues is not sufficient to achieve a lasting impact. Targeted promotion and monitoring of the identified issues has to be initiated in order to actually process new topics in standard committees and assure implementation. Although the project was welcomed and considered of general importance, the day-to-day basis of the standardisation committees requires promoters for new and important topics.

However, the development of this foresight approach initiated an internal process within the German standard setting organisation. This process aims to make foresight a continuous process, becoming an integral part of the internal work. With the help of qualitative and quantitative indicators and methods as described here, a regularly repeated foresight process will be developed, controlled by the DIN, refining to the originally process. It also focuses on the exchange of information on relevant topics and potential areas of standardisation. The results could provide input for possible new projects and cross link interested parties such as companies and institutions, mainly within standardisation committees. Also optimisation will be achieved by attending the identified issues in the implementation process. On this, additional human resources will be required in standardisation bodies – first, in order to recognise innovative topics at an early stage and second, to actively promote the topics in standardisation. The further development of the approach described in this paper goes beyond the idea of identification process. It will also contribute to further opening of standardisation processes, for all those engaged in the research and innovation landscape of the NIS. It retains the original objectives, still aiming for a more efficient contribution of standardisation as the instrument of transfer of invention and innovation into marketable products.

All in all, the chosen approach is the first systematic attempt for standardisation foresight. The approach is also suitable to be applied to other foresight issues, because of its modular configuration outlined before. It provides an extension to the established foresight methods and combines methods from foresight, S&T indicators, bibliometrics and text mining. Nevertheless, there is a variety of exogenous factors that affect actors in the innovation system.

However, the indicator approach is based on retrospective data. This means that disruptive developments could only marginally be identified by observation of classifications. The development of classifications tends to respond with a time lag to new developments and will be visible only when a certain critical mass level is reached. Such developments require analyses on the micro level. But arguing that, there is usually a phase of new technology developments, where a community building process takes place, prior to any standardisation activities, such developments should be visible when analysing S&T indicators.

5.1.1 A comparative case study: Delphi assessment and actual standard implementation in nanotechnology

In the following section the results of the Delphi survey assessments of identified future issues are compared to the published documents of the regulatory framework, e.g. standards and other technical rules. These results should add more information to the impact and practicability of the approach, the field of nanotechnology serves here as a case study. The section contains a qualitative analysis based on data entries in the database Perinorm of DIN, which contains official standard publications.

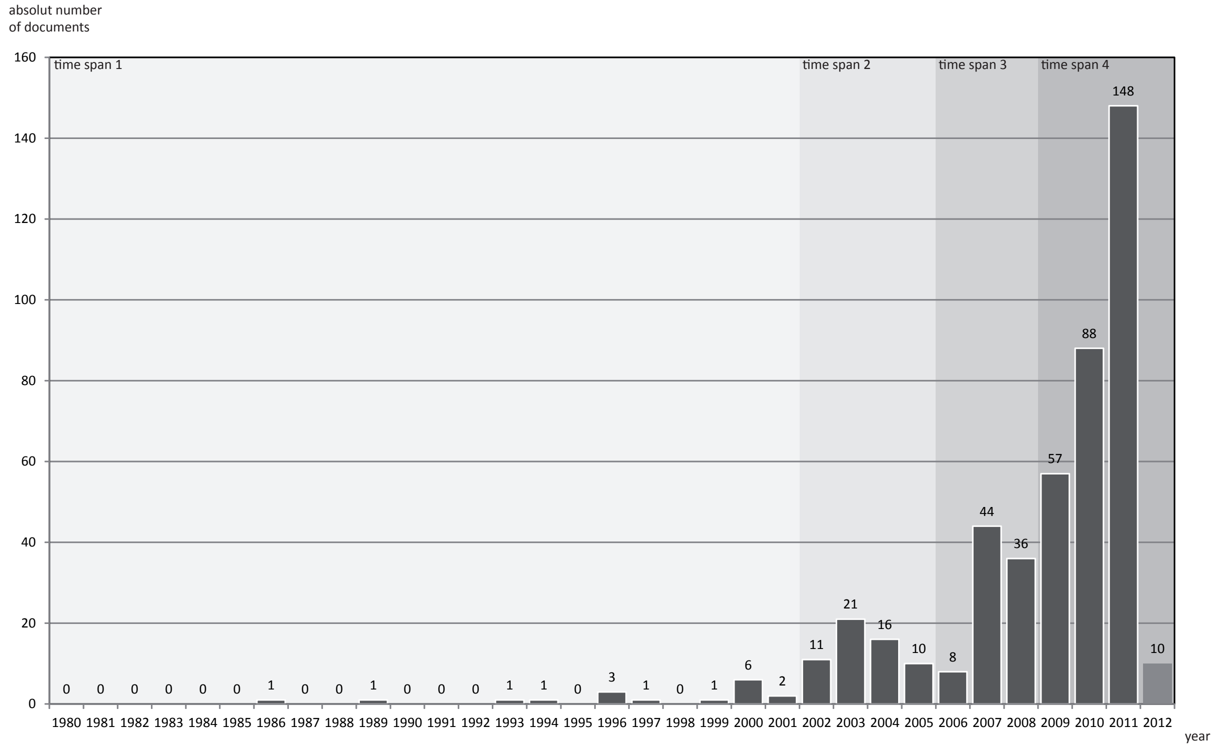
Since the international classification of standards (ICS) does not list a class for nanotechnology, a search strategy of keywords to identify the relevant documents in the database was conducted (see table 5.1in the annex). These include not only publications of finished formal standards (ST), but also previous draft concepts (DC) and revisions, regulations and administrative provisions (RG) and other technical rules (TD), to consider all available information about the regulatory framework. In addition, both documents on European and international level, and the national counterparts of these documents have been considered, covering the overall impact of the documents. From initial draft through to final implementation on the national level, on average 3 to 4 years have passed, in some exceptional cases it took even longer and the number of revised documents was higher (in one instance up to 12 years). Figure 5.1 shows the temporal progression of the publications of these documents in nanotechnology since 1980 for 22 countries.[4]

The following analysis selects first activities in the various countries and international levels on which further national reactions were initiated, which can indicate the origin of the technical proposals. Over the first period, from 1980 to 2001, peripheral topics of nanotechnology were covered, including topics such as methods of measurement of the magnetic properties of alloys in connection with amorphous and nanocrystalline materials (IEC 60404-6). Publications on this subject kept appearing starting in 1993 up to 2011. In addition, in 2000 a Committee Draft was

[4] AUSTRIA; BELGIUM; CANADA; CZECH REPUBLIC; DENMARK; GB; FRANCE; GERMANY; ITALY; JAPAN; LITHUANIA; NETHERLANDS; NORWAY; POLAND; RUSSIA; SLOVAKIA; SOUTH AFRICA; SPAIN; SWEDEN; SWITZERLAND; TURKEY; USA

published on instrumented indentation test for hardness and materials parameters of metallic materials (EN ISO 14577-1) was published, which is also a relatively peripheral topic. The first draft concept on particle size analysis with photon correlation spectroscopy was published in 1994 by ISO and the formal ISO standard was published in 1996 (ISO 13321).

Figure 5.1: Absolute number of published regulatory documents over time in the Perinorm database for 22 countries (survey date: March 2012).



Over the second period from 2002 to 2005, increased standardisation activity on magnetic properties of alloys around 2003 can be identified. Also, the US IEEE standard on test methods for the characterisation of organic transistors and materials (ANSI/IEEE 1620) was published in 2004.

Over the third period, between 2006 and 2008, there is a substantial increase in activities. Since the number continues to rise, the various topics are listed in tabular form (see table 5.1).

Between 2010 and 2012, the number of publications increased even more drastically (time span 4). This mainly includes national implementation of already published standards at international level. New topics are summarised in table 5.2.

The analysis shows that all published German standards are national equivalents of European or international drafts or standards. Only the other documents on topics cleanroom systems and construction chemicals are of German origin. In contrast, other countries like the U.S. (e.g. on terminology, handling of nanoparticles and organic transistors), Great Britain (e.g. terminology, good practice guides and labelling), France (e.g. regulations environmental and consumer information on foods) and Russia (e.g. nanoproduction, safety and cutting tools) have started national activities. This analysis underlines earlier findings of Blind & Gauch (2009). They show that despite a good research position (succeeding the U.S. and Japan) in nanotechnology science, Germany has failed in transferring its excellent starting position into standardisation (Blind & Gauch, 2009). On this, Blind & Gauch (2009) provide additional empirical proof for the time lag between the German research activities and its standardisation efforts. Interrelations between standardisation activities and e.g. the level of trade, the exact impact of such a time lag, however, should be content of further empirical investigation.

Table 5.1: Emerging issues over the period 2006-2008 (source: Perinorm, March 2012).

Year	Topic
2006	• First terminology standard relating to nanotechnology in the US (ASTM E 2456) • French technical rules on environment regulation with respect nanotechnology (3475516) • ISO standard on measurement and characterization of particles by acoustic methods with the use of ultrasonic attenuation spectroscopy (ISO 20998-1)
2007	• US standard guide for handling unbound engineered nanoscale particles in occupational settings (ASTM E 2535) • ISO standards on workplace atmospheres – Ultrafine, nanoparticle and nano-structured aerosols – Inhalation exposure characterization and assessment (ISO/TR 27628) • ISO standard on pore size distribution and porosity of solid materials by mercury porosimetry and gas adsorption (NEN-ISO 15901-2) • First draft concept of ISO on terminology and definitions for nano-objects (ISO/TS 27687) Increase in activities in GB on the following topics: • Standard on good practice guides for manufactured nanomaterials (PD 6699-1, PD 6699-2) • Standard on guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles (PAS 130) • Terminology standard for medical, health and personal care applications of nanotechnology (PAS 131) • Terminology standard for the bio-nano interface (PAS 132) • Terminology standard for common nanoscale measurement and instrumentation (PAS 133) • Terminology standard for carbon nanostructures (PAS 134), nanofabrication (PAS 135) and nanomaterials (PAS 136)
2008	Increased US activities on health aspects and measurement: • Standard test method for analysis of haemolytic properties of nanoparticles (ASTM E 2524) • Standard test method for evaluation of the effect of nanoparticulate materials on the formation of mouse granulocyte-macrophage colonies (ASTM E 2525) • Standard test method for evaluation of cytotoxicity of nanoparticulate materials (ASTM E 2526) • Commission recommendation of 7 February 2008 on a code of conduct for responsible nanosciences and nanotechnologies research (08/345/EGEmpf) • German VDI directive on cleanroom systems and molecular contamination (VDI 2083 page 14) • IEC draft concept on guidelines for single wall carbon nanotube specifications for electro technical applications (IEC 62565) • ISO standard on health and safety practices in occupational settings relevant to nanotechnologies (ISO/TR 12885) • ISO draft concept on ergonomics of human-system interaction – Human-centred design for interactive systems (ISO/DIS 9241-210)

Table 5.2: Emerging issues over the period 2009-2012 (source: Perinorm, March 2012).

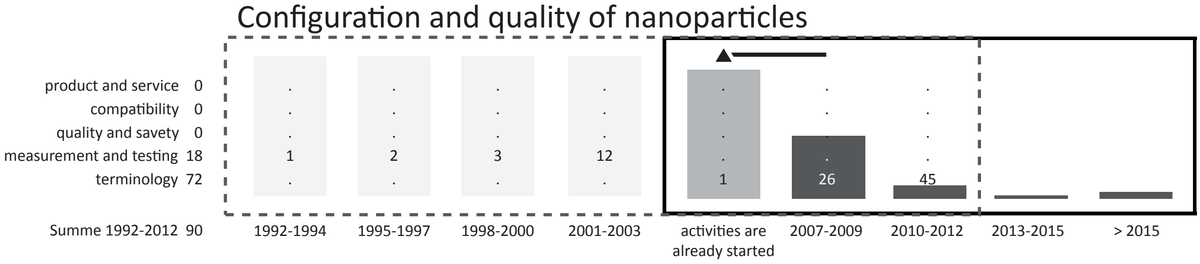
Year	Topic
2009	• German status report on nanotechnology in construction chemicals (DBCh Nanotechnology)
2010	• ISO standard on methodology for the classification and categorization of nanomaterials (ISO/TR 11360) • ISO draft concept on vocabulary for healthcare - diagnostics and therapeutics (ISO/TS 80004-7)
2011	Increased Russian activities on nanoproduction, safety and on cutting tools: • Standard on requirements of environmental management systems for nanoproduct producing organizations (GOST R 54336) • Standard on requirements of occupational safety management systems for nanoproduct producing companies (GOST R 54337) • Standard on requirements for quality management systems for nanoproduct producing organizations (GOST R 54338) • Enterprise management in nanoindustry (GOST R 54617.1) and especially hazard identification (GOST R 54617.2) • Nanocoatings of cutting tools based on diamond and on cubic boron nitride (GOST R 54473) • French regulation on consumer information on foods and amending council regulations (EC) (RG 1169/2011)
	Activities on European and international level: • Standard on nanomaterial risk evaluation (ISO/TR 13121) • Draft concept on semiconductor / micro-electromechanical devices – Bulge test method for measuring mechanical properties of thin films (EN 62047-17) • Standard on chemical surface analysis – characterisation of nanostructured materials (ISO/TR 14187) • Standard on material specifications – Guidance on specifying nano-objects (ISO/TS 12805) • Draft concept on description, measurement, and dimensional quality parameters of artificial gratings (IEC 113/123/CD) • Draft concepts on nanomanufacturing – large scale manufacturing for nanoelectronics (IEC 113/127/CD) and key control characteristics – Luminescent nanomaterials - quantum efficiency IEC (113/130/CD) • Standard on the Determination of elemental impurities in samples of carbon nanotubes using inductively coupled plasma mass spectrometry (ISO/TS 13278)

To supplement the analysis a final assessment of the applicability of the approach was made. On this, standardisation issues identified through the chosen foresight approach were compared with the above-described publications in the database Perinorm. In particular, the estimated timing of standardisation activities of the Delphi survey was matched with the publication dates of the standardisation documents, considering all 22 countries included in the database. On average a standardisation process takes a total of 3 years. Having this in mind, activities should start before the publication is presented. Involved experts were aware of these activities and could affect the estimates according to these activities. One point worth noting, however, is the fact that there can be duplication of documents for the adoption of international standards documents in the national stocks. This must be considered when cautiously interpreting counted documents.

The field of nanotechnology was one of the first topics identified by the indicator approach and examined in an in-depth Delphi survey of experts in 2006. Here, nearly 1,500 experts were identified. At the first Delphi round 95 people participated, in the second round only 49 respondents were left. A total of 59 standardisation issues in 13 subjects categories were identified and assessed. For the comparative analysis, individual items of the Delphi surveys were selected, which already have equivalents in the publications. Overall, 17 subject issues of the Delphi survey could be assigned. The results have been illustrated in separate figures. The figures show on the right hand side the results of Delphi survey on nanotechnology form the year 2006 (first survey round) including bar charts of response frequencies (maximum number is 50 respondents). This is not intended for representing the exact results, but to illustrate the distribution for the different standardisation issues. In addition to this, the quartiles of the distributions have been illustrated. The left end of the line above the bars denotes the 25% quarter, the right end of the line indicates the 75% quarter and the triangle indicates the media. The left hand side of the figure shows the results of the publication analysis. Counting all standards and corresponding drafts, illustrates the timespan of standardisation activities. However, publications cannot be used to assess starting points of activities or how much time has elapsed until the final publication of the documents. The number of documents is displayed as a number matrix, framed by a dashed box and sorted according to their standardisation type (starting from the bottom: terminology, measurement and testing, quality and safety, as well as product compatibility and service).

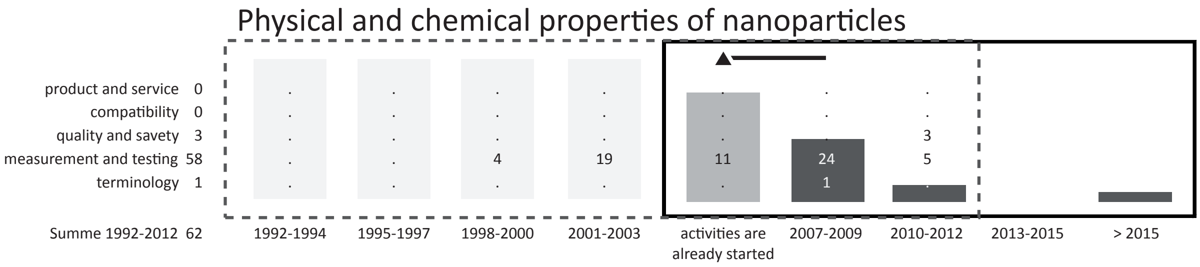
According to the experts, standardisation activities for "configuration and quality of nanoparticles" were planned or started in 2006. These should have continued in the following 3 years (i.e. 2007–2009). According to the respondents primarily a need for standards of measurement and testing and technology standards but also quality and safety standards at international level was indicated. The analysis of standardisation and other documents evidences different standards on particle size analysis and terminology and definitions for nanoparticles, vocabulary (on core terms, nano-objects, nanostructured materials, nanomaterials, nano-bio interface), materials specifications, classification and categorisation of nanomaterials, taxonomy, and key control characteristics, ranging from 1994 to 2012. The results are illustrated in figure 5.2. The comparison of the results documents activities before 2006. However, activities on terminology mainly occurred later than the experts of the Delphi survey had indicated. This development in turn further supports for the argument that a community-building process should take place well before standardisation can support the technical development.

Figure 5.2: Comparative analysis for the item "configuration and quality of nanoparticles".



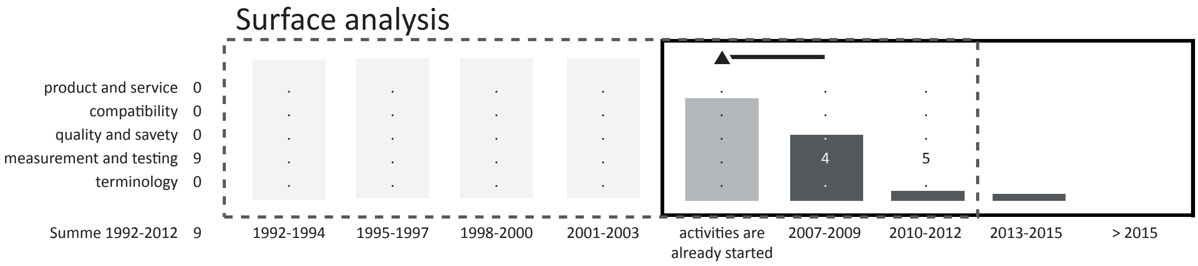
Item "physical and chemical properties of nanotechnology": The majority of the experts of the Delphi survey indicated that standardisation activities on this subject already started or were already planned in 2006, or were necessary in the years 2007 to 2009. A need for standards for measuring and testing technology, terminology and quality and safety standards especially at international level was indicated. The survey also included items on "non-destructive measurement technology" and "chemical analyses". Results show the same response patterns and did not differ significantly from the described item above. Since the items are very similar in content, the documents could not be distinguished in the comparative analysis of the publications of standards and other documents. Therefore, these three aspects were considered together and compared with the distribution of the first item. The results are illustrated in figure 5.3. From this, the following documents could be identified: In 2006 the measurement and characterization of particles by acoustic methods; in 2007 terminology for common nano-scale measurement and instrumentation; in 2009 state system for ensuring the uniformity of measurements instruments measuring the characteristics of ultraviolet radiation of technological testing of nanophotolitography; and description, measurement and dimensional quality parameters of artificial gratings in 2011.

Figure 5.3: Comparative analysis for the items "physical and chemical properties of nanotechnology", "destruction-free measurement technology" and "chemical analyses".



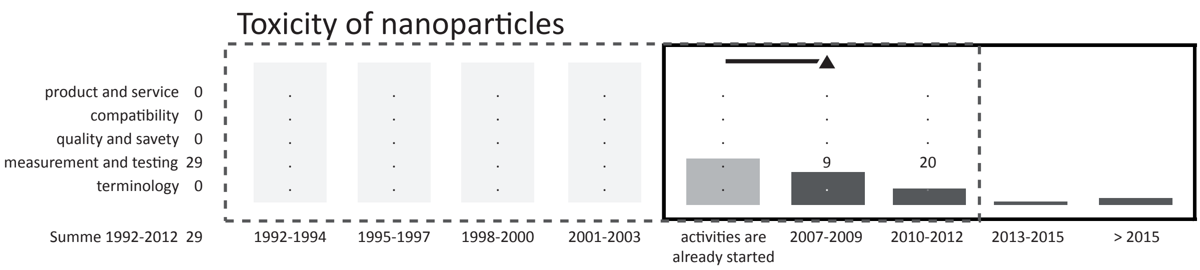
For the item "surface analysis" the result of the Delphi survey showed that activities had already started or had been planned in 2006, referring primarily to measuring and testing standards, quality and safety standards and terminology at the international level. Here, however, corresponding published documents can only be found for the period 2007-2012 (see figure 5.4): In the 2007 evaluation of pore size distribution and gas adsorption porosimetry and in 2011 by chemical surface analysis of nanomaterials.

Figure 5.4: Comparative analysis for the item "surface analysis".



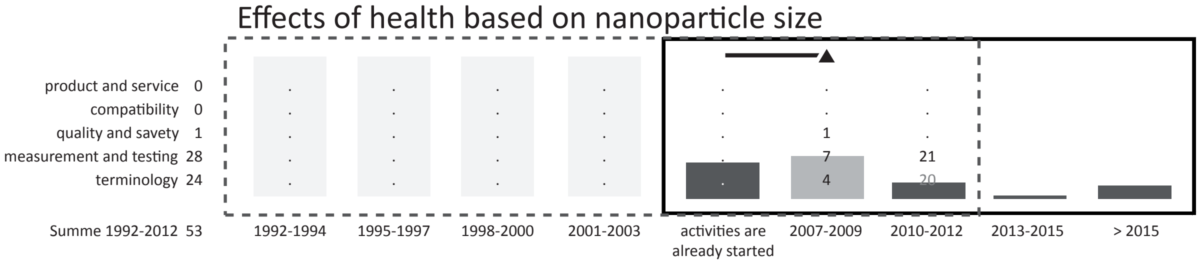
The Delphi assessments for the items "toxicology of nanoparticles" were not so clear concerning the temporal priority. The experts envisioned, however, a need for measurement and testing as well as quality and safety standards on an international level. The Item "overcoming barriers of skin and cell/boundaries by nanoparticles" showed similar assessments. Here the necessary activities were dated from 2007 to 2009, a bit later. The comparative analysis revealed the majority of publications for 2010-2012: Including a standard test method for evaluation of cytotoxicity of nanoparticulate materials in porcine kidney cells and human hepatocarcinoma cells; for analysis of haemolytic properties of nanoparticles; and for evaluation of the effect of nanoparticulate materials on the formation of mouse granulocyte-macrophage colonies in 2008; and an endotoxin test on nanomaterial samples for in vitro systems in 2009 and their national documents in the time period from 2010 to 2012 (see figure 5.5).

Figure 5.5: Comparative analysis for the items "surface analysis" and "overcoming barriers of skin and cell/boundaries by nanoparticles".



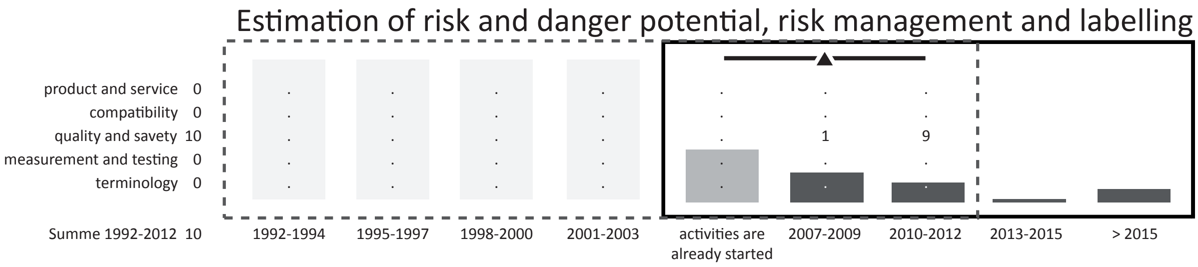
For the item "effects of health based on nanoparticle size, e.g. asbestos" the evaluated time period for standardisation activities is 2007 to 2009. The experts especially indicated a need for quality and safety but also measurement and testing standards. During the same period, however, three important documents could be identified: Characterisation of nanoparticles in inhalation exposure chambers for inhalation toxicity testing, health risks of nanomaterials after inhalation, and generation of metal nanoparticles for inhalation toxicity testing, all in 2009. The increased number of documents in the period 2010–2012 mainly concerns national implementation of these three documents (see figure 5.6).

Figure 5.6: Comparative analysis for the item "effects of health based on nanoparticle size".



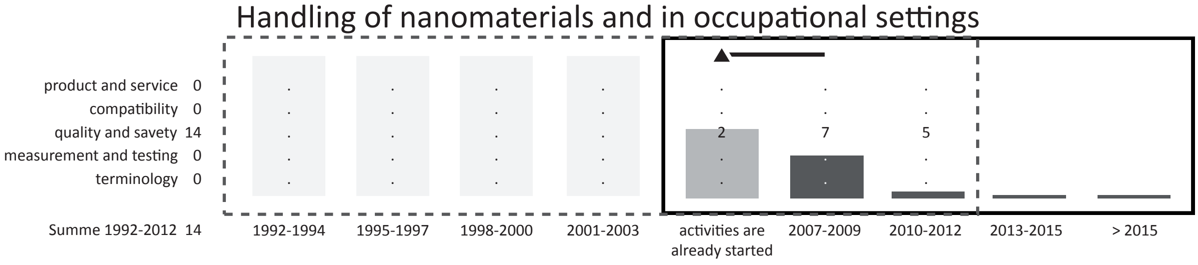
For the item "estimation of risk and potential danger, risk management and labelling", the experts in the Delphi survey stated that activities had already started or were planned in 2006. However the analysis of the Perinorm database revealed only little activity until 2011.E.g. a standard on guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles in 2007 and a commission recommendation for a code of conduct for responsible research in nanosciences and nanotechnologies in 2008 could be identified. From 2011 onwards documents were on nanomaterial risk evaluation, enterprise management in nano-industry, and identification of hazards. The results are highlighted in figure 5.7.

Figure 5.7: Comparative analysis for the item "Estimation of risk and danger potential, risk management and labelling".



To improve readability the remaining four items have been summarised, including: "Handling of nanomaterials and in occupational settings" (see figure 5.8), "manufacturing" (see figure 5.9), "nanotechnology in healthcare and medication" and "nanoparticles in cosmetics" (see figure 5.10), and "miniaturisation of computer chips, computer memory, and optoelectronics" (see figure 5.11).

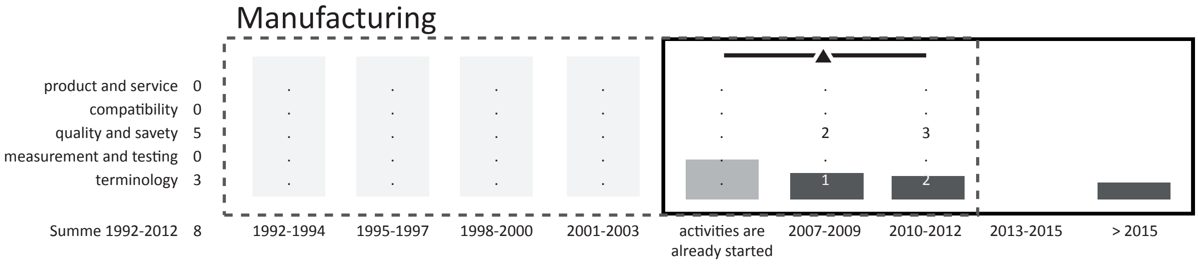
Figure 5.8: Comparative analysis for the item "configuration and quality of nanoparticles".



Corresponding documents:

- Guide for Handling Unbound Engineered Nanoscale Particles in Occupational Settings (ST) in 2006;
- Code of conducing responsible nanosciences and nanotechnologies research in 2008;
- Health and safety practices in occupational settings relevant to nanotechnologies in 2008;
- Informations on Nanomaterialien am Arbeitsplatz (TD) in 2010.

Figure 5.9: Comparative analysis for the item "configuration and quality of nanoparticles".



Corresponding documents:
2007

- Terminology for nanofabrication;
- Good practice guide for specifying manufactured nanomaterials;
- Guide to safe handling and disposal of manufactured nanomaterials;
- Enterprise management in nanoindustry.

2010

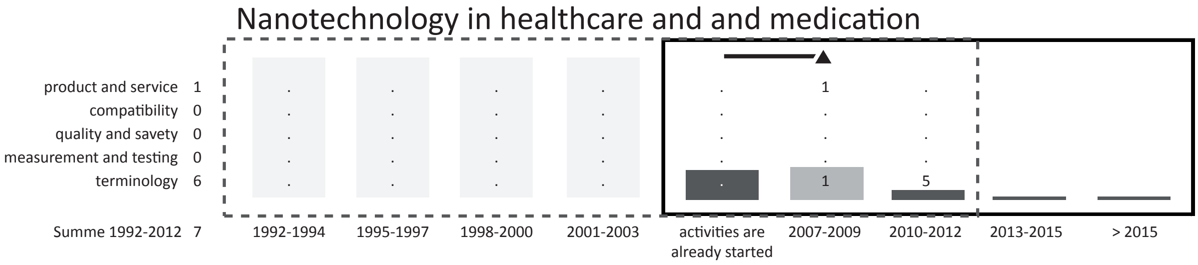
- Nanomanufacturing - Key control characteristics;

2011

- Nanomanufacturing - Large scale manufacturing for nanoelectronics;

- Requirements for quality management systems for nanoproduct producing organisations.

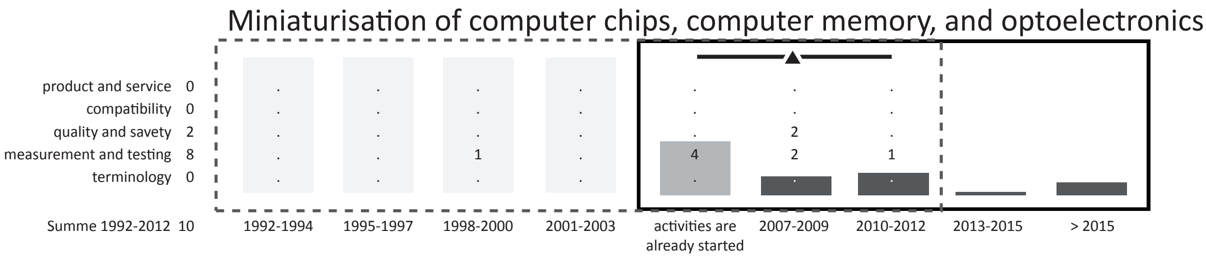
Figure 5.10: Comparative analysis for the item "configuration and quality of nanoparticles".



Corresponding documents:

- Terminology for medical, health and personal care applications of nanotechnology in 2007;
- Regulations on cosmetic products in 2009;
- Vocabulary: Healthcare - Diagnostics and therapeutics in 2010.

Figure 5.11: Comparative analysis for the item "configuration and quality of nanoparticles".



Corresponding documents:

- Terminology for medical, health and personal care applications of nanotechnology in 2007;
- Standard test methods for analyzing organic contaminants on silicon wafer surfaces by thermal desorption gas chromatography in 1999;
- Test methods for the characterization of organic transistors and materials in 2004;
- Directive on clean room systems and molecular contamination in 2008;
- Semiconductor devices - micro-electromechanical devices - Bulge test method for measuring mechanical properties of thin film in 2011.

Two other items "nanotechnology in the food sector" and "nanotechnology in the construction industry" could be identified in the Perinorm database, but in each case only one country started regulating activities. Because of this low amount of data, the visualisation was dispensed. A consideration of relevant DIN standardisation committees shows, that a total of 11 national standardisation committees[5] and 7 contact persons could be connected to the above listed standardisation items, which influences the integrated processing of the subject.

However, summarising the comparative case study results, the selected foresight approach, allows to timely identify important topics and assess approximate time periods for their implementation. Other topics of the Delphi survey also provide important clues for the further course of standardisation efforts. However, the analysis shows that activities in terminology standardisation started later than estimated by the experts. Actually, the process started with the development of measurement and testing standards, different to the underlying model implications developed by Blind & Gauch (2009). The analysis also shows how difficult detailed assessment of foresight activities can be. Why and when some issues are processed, or why topics are excluded, cannot be answered by this analysis. Also, direct responses to the foresight results in the specific standard committees are not known. Additional semi-structured interviews could provide additional insights on these questions.

5.2 Concluding remarks

For regular standardisation work the identification of new fields and its standardisation issues is particularly challenging. Especially, if various standardisation committees are necessary to process this issue or the topic lacks appropriate committee structures. In these cases, important impulses from science and technology are often poorly absorbed in standardisation processes or with a great delay. Here, the considered approach for standardisation foresight offers its greatest potential. However, a simple identification process is not sufficient to initiate important standardisation processes. The following standardisation activities should also be stimulated. The comparative case study analysis in the field of nanotechnology further indicates that early preparation and a more intense exchange among experts is necessary.

[5]DKE/K 141 – Nanotechnology; DKE/K 171 - Magnetic Alloys and Steels; DKE/K 631 – Semiconductor Devices; NA 023-00-04-05 GAK – Working Group – User Interfaces; NA 062-01-41 AA - Hardness Testing for Metals; NA 095-03-01-01 AK – Particulate Matter; NA 062-08-16 AA – Surface Chemical Analysis and Scanning Probe Microscopy; NA 062-08-17-01 UA – Terminology; NA 062-08-17-02 UA – Test Methods; NA 062-08-17-03 UA – Health and Environmental Aspects; NA 062-08-17-04 UA – Materials Specifications.

Table 5.3: Search strategy for the Perinom data base.

Field	Search item
full-text search	nano* WITHOUT (nanofiltra* OR nano-filtra* OR nanogram* OR nanomet* OR nanohenry* OR nanosekund* OR nanosecond* OR nanosz* OR nanozky OR nanosleep OR nanomole OR nanosu OR nanosem OR nano-sekunden* OR NaNO2 OR nanoperm* OR nanojoule* OR nanosi OR nanosov* OR nanosy OR petroleum OR erdöl)
OR	
document number	"IEC 113/101/CD" OR "IEC 113/102/CD" OR "IEC 113/104/DTS" OR "CEN ISO/TS 13830" OR "CEN ISO/TS 13830:2011" OR "CEN ISO/TS 27687" OR "CEN ISO/TS 27687:2008" OR "CEN ISO/TS 27687:2009" OR "CEN ISO/TS 27687:2010" OR "EN 4592" OR "EN 4592:2006" OR "EN 60404-6" OR "EN 62047-17" OR "EN ISO 1043-2" OR "EN ISO 10801" OR "EN ISO 10801:2010" OR "EN ISO 10801:2011" OR "EN ISO 10808" OR "EN ISO 10808:2010" OR "EN ISO 10808:2011" OR "EN ISO 14577-1:2005" OR "EN ISO 14577-4" OR "EN ISO 14577-4:2007" OR "EN ISO 28439" OR "EN ISO 28439:2011" OR "EN ISO 29701" OR "EN ISO 29701:2010" OR "EN ISO 29701:2011" OR "EN ISO 9241-210" OR "EN ISO 9241-210:2010" OR "EN ISO 9241-210:2011" OR "EN-IEC 60404-6:2003" OR "EN-ISO 10801:2009" OR "EN-ISO 10801:2010" OR "EN-ISO 10808:2010" OR "EN-ISO 14577-4:2005" OR "EN-ISO 14577-4:2007" OR "EN-ISO 28439:2009" OR "EN-ISO 28439:2011" OR "EN-ISO 29701:2009" OR "EN-ISO 29701:2010" OR "EN-ISO 9241-210:2010" OR "IEC 113/100/PAS" OR "IEC 113/106/DTS" OR "IEC 113/118/DTS" OR "IEC 113/123/CD" OR "IEC 113/127/CD" OR "IEC 113/130/CD" OR "IEC 113/133/DTS" OR "IEC 113/27/CD" OR "IEC 113/52/DTS" OR "IEC 113/53/CD" OR "IEC 113/58A/FDIS" OR "IEC 113/60/DTR" OR "IEC 113/79/DTS" OR "IEC 113/88/DTS" OR "IEC 113/94/DTS" OR "IEC 113/96/DTS" OR "IEC 60404-6" OR "IEC 62565" OR "IEC 62607-2-1" OR "IEC 62607-3-1" OR "IEC 62622" OR "IEC 62624" OR "IEC 62624:2009" OR "IEC 62659" OR "IEC 68/212/CD" OR "IEC/PAS 62565-2-1" OR "IEC/PAS 62565-2-1:2011" OR "IEC/TR 62517:2009" OR "IEC/TS 62607-2-1" OR "IEC/TS 62622" OR "IEEE 1620" OR "IEEE 1650" OR "ISO 10801" OR "ISO 10801:2010" OR "ISO 10801:2011" OR "ISO 10808" OR "ISO 10808:2010" OR "ISO 10808:2011" OR "ISO 12025" OR "ISO 13318-2:2007" OR "7 ISO 13319:2007" OR "ISO 13319:2007-09" OR "ISO 13320:2009" OR "ISO 13320:2009-12" OR "ISO 13321" OR "ISO 13321:1996" OR "ISO 13321:2000" OR "ISO 13321:2004" OR "ISO 13322-2:2006" OR "ISO 14488:2008" OR "ISO 14577-1" OR "ISO 14577-1:2004" OR "ISO 14577-4" OR "ISO 14577-4:2007" OR "ISO 15900:2009" OR "ISO 15901-1:2006" OR "ISO 15901-2:2007" OR "ISO 15901-3:2007" OR "ISO 20998-1:2006" OR "ISO 21501-1:2009" OR "ISO 21501-2:2007" OR "ISO 21501-3:2007" OR "ISO 21501-4:2007" OR "ISO 22412:2008" OR "ISO 28439" OR "ISO 28439:2011" OR "ISO 29701" OR "ISO 29701:2010" OR "ISO 80004-1" OR "ISO 9241-210" OR "ISO 9241-210:2010" OR "ISO 9276-3:2008" OR "ISO 9276-6:2008" OR "ISO 9277:2010" OR "ISO/DIS 10801" OR "ISO/DIS 10808" OR "ISO/DIS 11952" OR "ISO/DIS 12025" OR "ISO/DIS 13321" OR "ISO/DIS 28439" OR "ISO/DIS 29701" OR "ISO/DIS 9241-210" OR "ISO/FDIS 10801" OR "ISO/FDIS 10808" OR "ISO/FDIS 28439" OR "ISO/FDIS 29701" OR "ISO/FDIS 9241-210" OR "ISO/IEC 10797" OR "ISO/TR 10929" OR "ISO/TR 10929:2012" OR "ISO/TR 11360" OR "ISO/TR 11360:2010" OR "ISO/TR 12802" OR "ISO/TR 12802:2010" OR "ISO/TR 12885" OR "ISO/TR 12885:2008" OR "ISO/TR 12885:2010" OR "ISO/TR 13121" OR "ISO/TR 13121:2011" OR "ISO/TR 14187" OR "ISO/TR 14187:2011" OR "ISO/TR 27628" OR "ISO/TR 27628:2007" OR "ISO/TR 27628:2010" OR "ISO/TS 10797" OR "ISO/TS 10798" OR "ISO/TS 10798:2011" OR "ISO/TS 10867" OR "ISO/TS 10867:2010" OR "ISO/TS 10868" OR "ISO/TS 10868:2011" OR "ISO/TS 11251" OR "ISO/TS 11251:2010" OR "ISO/TS 11308" OR "ISO/TS 11308:2011" OR "ISO/TS 11751" OR "ISO/TS 11888" OR "ISO/TS 11888:2011" OR "ISO/TS 12805" OR "ISO/TS 12805:2011" OR "ISO/TS 13278" OR "ISO/TS 13278" OR "ISO/TS 13278:2011" OR "ISO/TS 27687" OR "ISO/TS 80004-1" OR "ISO/TS 80004-1:2010" OR "ISO/TS 80004-3" OR "ISO/TS 80004-3:2010" OR "ISO/TS 80004-4" OR "ISO/TS 80004-4:2011" OR "ISO/TS 80004-5" OR "ISO/TS 80004-5:2011" OR "ISO/TS 80004-7" OR "ISO/TS 80004-7:2011" OR "ASTM F 1982" OR "DIN EN ISO 1043-2" OR "DIN EN ISO 1043-2" OR "DS/EN 4592" OR "DSF M256079 " OR "DSF M256774 " OR "DSF M257665" OR "GOST R 8.712" OR "NEN-EN 4592:2006 en" OR "NF L16-010" OR "OENORM EN 4592" OR "OENORM EN 4592" OR "PN-EN 4592:2006 (U)" OR "SS-EN 4592:2006" WITHOUT ("DSF M257631" OR "NF S94-062-1" OR "NF ISO 13779-*" OR "459-2" OR "EN ISO 10432")

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