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Identification of future fields of standardisation: An explorative application of the Delphi methodology

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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, we describe the process of identifying future fields of standardisation.

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 choosen. 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 concludes with the assessment of the chosen approach and give 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.

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 [1] 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 a flow of new technologies over a longer period of time [2] 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 [3]). It also includes the capabilities or the economic competence of the actors of the system to generate, diffuse and commercialise technologies [4]. Here standardisation can enhance these capabilities.

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By the term standardisation, we broadly mean the process of developing and implementing technical standards. By including all interested stakeholders, the standardisation process aims ad 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 recognized institution, such as a national standard body (NSB).[2] 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, we developed a supplementary indicator-Delphi approach for conducting systematic foresight studies for the identification of future fields of standardisation. 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 [5] 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 paoer especially focus 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 dicussed 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 as follows. Section 2 gives practical preliminary considerations for standardisation foresight. Section 3 provides theoretical background on science and technology indicators, the Delphi technique, and the role of standardisation in the R&D process. In Section 4 will give a more general description of the method. It is followed by a comparative analysis of conducted case studies. In addition, modifications made to the approach, addressing some practical issues will be described. The paper concludes 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.

2. Practical preliminary considerations for standardisation foresight

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 [6]. 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 [6].

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 a 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 [7,8]. Table 1 summarises these similarities. Considering all these points, the Delphi technique seems to be an adequate method for determining future standardisation issues.

In both processes the selection of panellists or stakeholders is a matter of high importance and presents a difficult task. For Delphi approaches, Härder [9] 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 on two typologies (see [1,9]). The typology by Martin [1] 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 programme; and (f) communication and education within the research community. The typology by Härder [9] 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.

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

Table 1
Similarities between standardisation processes and Delphi surveys.

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

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. 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. The majority of experts consider foresight to be a collective and consultative process with the process itself being equally or even more important than the outcome. The aim is also to achieve an 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. Theoretical 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.

3.1. 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 [10]. 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) [10]. 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 [11]. Despite the R&D process being neither linear nor simple and the borders between the different phases being unclear and sometimes overlapping [11,12], general empirical evidence that support this simple model can be found. Nevertheless, S&T indicators must be seen as supplementary information [11,13].

In the following the slightly modified system of science and technology indicators introduced by Grupp [14] is also referred (see also Fig. 1). It adapts the concept of the linear phase model of R&D. 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 [11]. For industrial development this is not consistently the case. Patent application data may be used for measuring applied research and development output. Since patent applications are also influenced by various other strategic entrepreneurial decisions, they are also suitable for detecting corporate regional strategies [11].

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 [3,4,15,16]), the innovation system includes all important economic, social, political, organisational, institutional and other factors that influence development, diffusion and the use of innovations [15,16]. According to Fagerberg et al. [15] 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 [4,15]. In addition, the behaviour of organisations is shaped by other institutions such as laws, standards, rules, norms and routines, which constitute incentives and obstacles for innovation.[3] In this paper the focus is put only on national innovation activities. This includes all actors and activities of the economy which are necessary for industrial and commercial innovation and

[3] 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 were 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 were described in [15] in more detail.

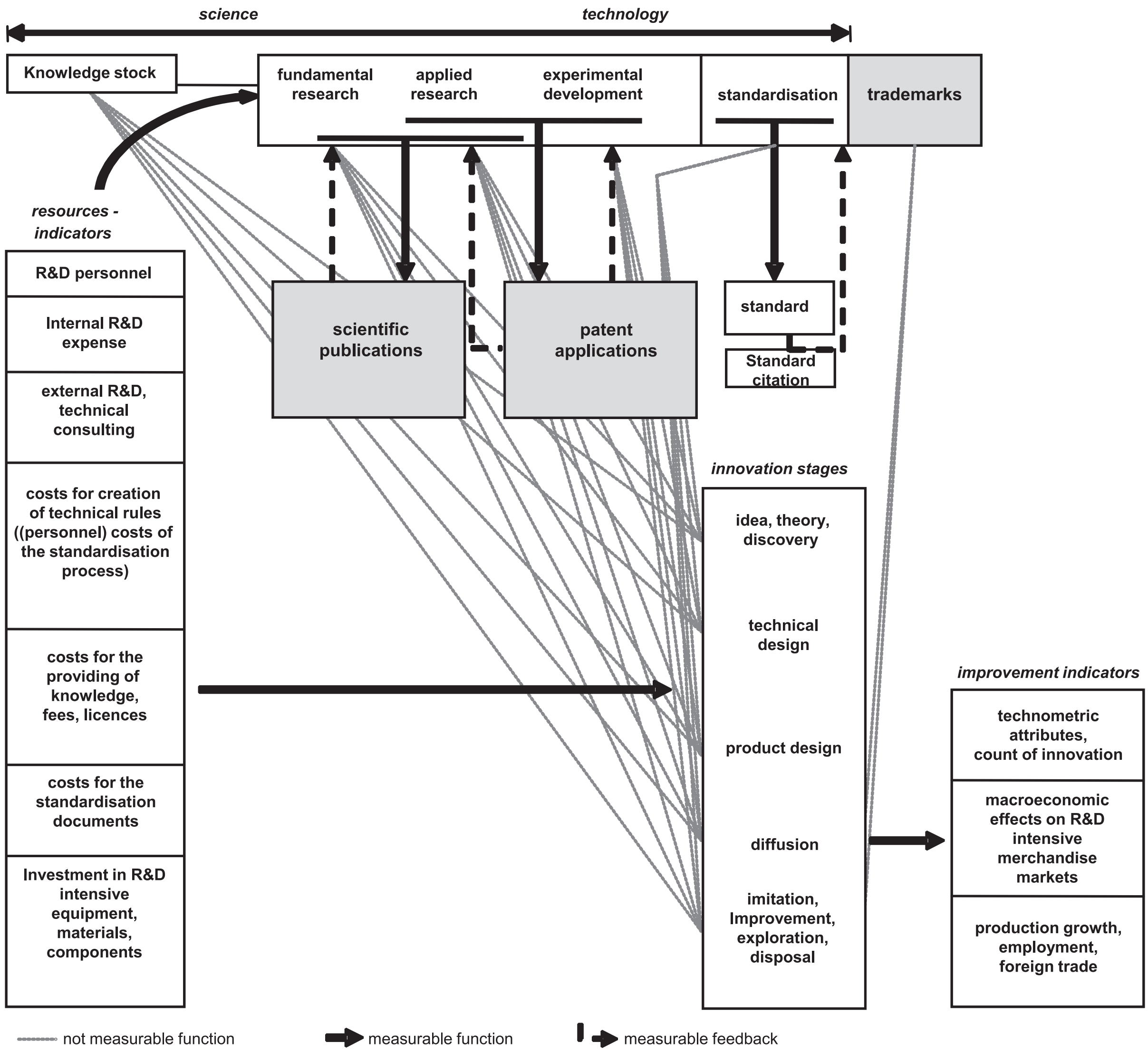

Fig. 1. System of science and technology indicators, modified according to [14].

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 [4]. The most important components of the national innovation systems are the industrial system, education and research system, and the political system and intermediaries [3]. As Arnold et al. [3] 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 firms operate.

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 [11], citation analysis for the quantitative assessment of the performance of research [17] or identification of research groups using publication analysis [18]. 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 [10,11,19].

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 [20]. 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 [8,21,22]) the Delphi technique has become a widely used tool in a variety of disciplines [23] and all kinds of application areas to assess and predict future developments for measuring and aiding forecasting and decision making [23]. 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 [24–26], 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 [27]. 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 [8,28,29].

Recent studies however consider the potential performance of Delphi and have demonstrated the validity and long-range accuracy of the Delphi technique [25,27]. 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 [24] found that in practical applications, the number of rounds varies from two to ten (see [30,31]). 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 judgments. Paranté & Anderson-Paranté [32], Brockhoff [33] and Rowe et al. ([20,34]) showed that judgmental accuracy generally improves over rounds. In an evaluation of Woudenberg [24] nearly all investigated studies confirm this improvement. In addition, most improvement takes place between the first and the second estimation round (see [29,35,36]). In some studies, accuracy further increased after the second estimation round (see [26], where 4 iterations were needed). Yet convergence of opinion will not imply improved forecasting accuracy in every case [20]. 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 [20,37]).

(2) The optimal type of feedback: Primary aim of Delphi is to reduce the conformity pressure [20] exerted from majorities or dominant individuals. Any judgement change should be caused by new information only [24]. The effects of different types of feedback were investigated mainly by [20,38,39]. These include various types of feedback, such as statistical summaries of panel judgments, varying from a single number to complete distribution [24] (see [40,41]) as well as reason feedback or arguments along with their numerical estimates [20]. The results of Rowe et al. [20] 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 [20]. Woudenberg [24] comes to a similar conclusion: A host of support can be found for the assertion that statistical feedback induces conformity. Nevertheless, Woudenberg [24] himself 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 [32,38]). In summary, Rowe et al. [20] 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 member, since the quality of the Delphi results depends strongly on the expertise of involved experts. Therefore, Okoli & Pawlowski [27] as well as Delbecq et al. [42] 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 [27]), 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 [33] 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. [43] 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 a debate. Within this context, the relation between accuracy and self-ratings has been investigated, leading to opposite results (see [43–45]). 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 [20,32,38]. On the contrary, Woudenberg [24] claims the lack of directly relevant information in uncertain situations determines judgments 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 [46–48]). The aim of the iterative questioning in consecutive rounds is to find a consensus, i.e. to reach certain estimation conformity. This consensus can not 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.

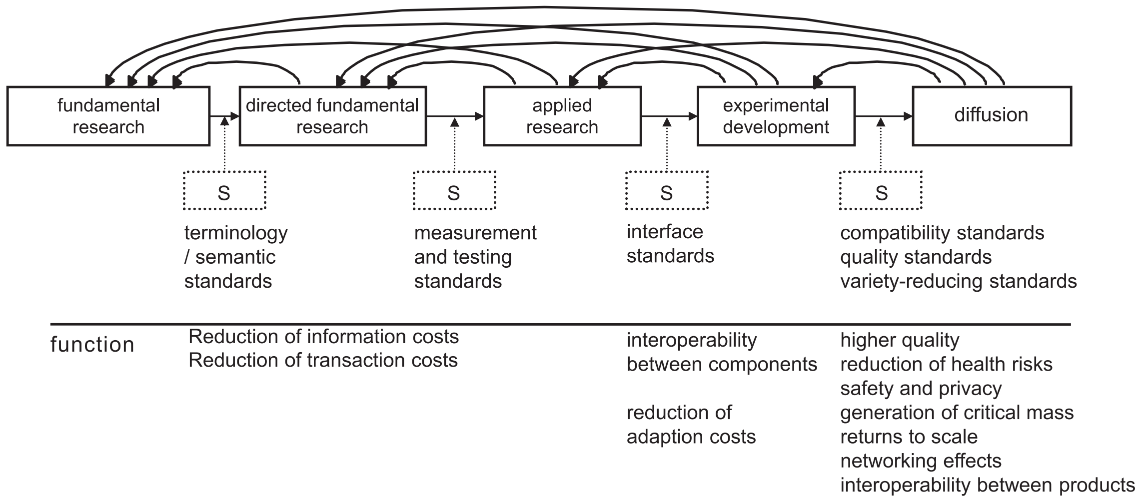

Fig. 2. Standards in the research and innovation process (see [49]).

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 [5,49,50]). 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 [49].

In short, different types of standards are linked to specific stages of the R&D process [49] (see Fig. 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.[4] 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 [49]. Furthermore, they simplify the transfer of knowledge from basic to applied research. For this, transfer measurement and testing standards are needed, which allow 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 [50]. More economic functions can be shown. The contribute to the increasment of quality, 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 [51]. As Blind [52] 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 [53], de-jure standards and technical guidelines contribute significantly to the international competitiveness of entire industries of a country by affecting economic growth and foreign trade, see [54,55].

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 paradigms, adding to the diffusion of one technological solution. [56].

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-

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

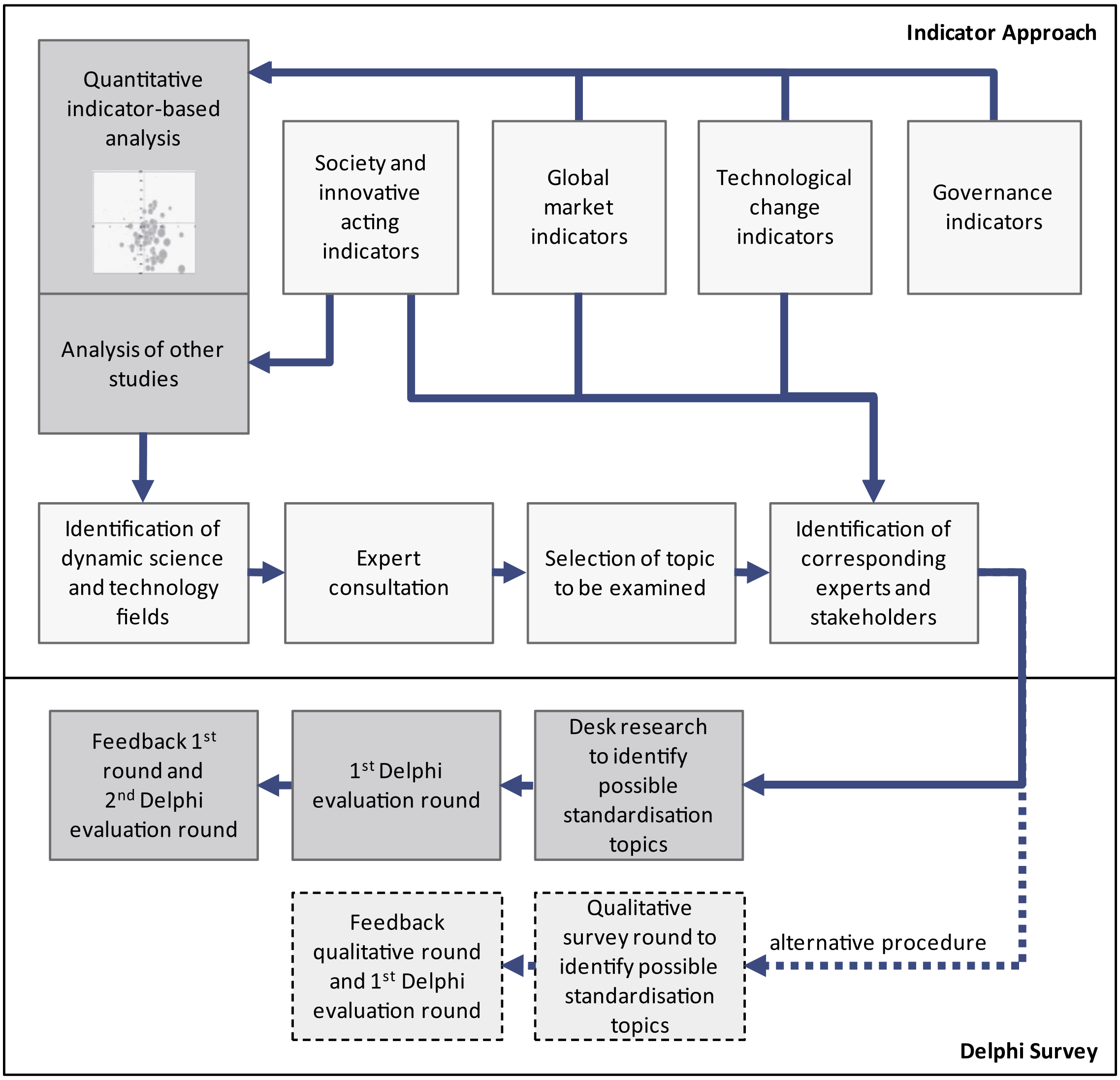

Fig. 3. Sequential steps of the approach.

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 Fig. 3.

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 are suitable, which facilitate the identification and comparison of more general dynamic future technological developments in various disciplines. These include indicators that allow statistic 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, Härder [9] 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 with 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 representative [6]. The German Institute of Standardisation (DIN) 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 has 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. Fig. 4 combines the diagram of the actors and stakeholders of standardisation in the national innovation system (see [3]) 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 [1], 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 as well are included, because standards promote the diffusion of innovation and also affect acceptance of users. Thus, the fourth category comprises survey-based society indicators, such as general innovation constraints and the technological acceptance on the demand side as well as online networks and communities.

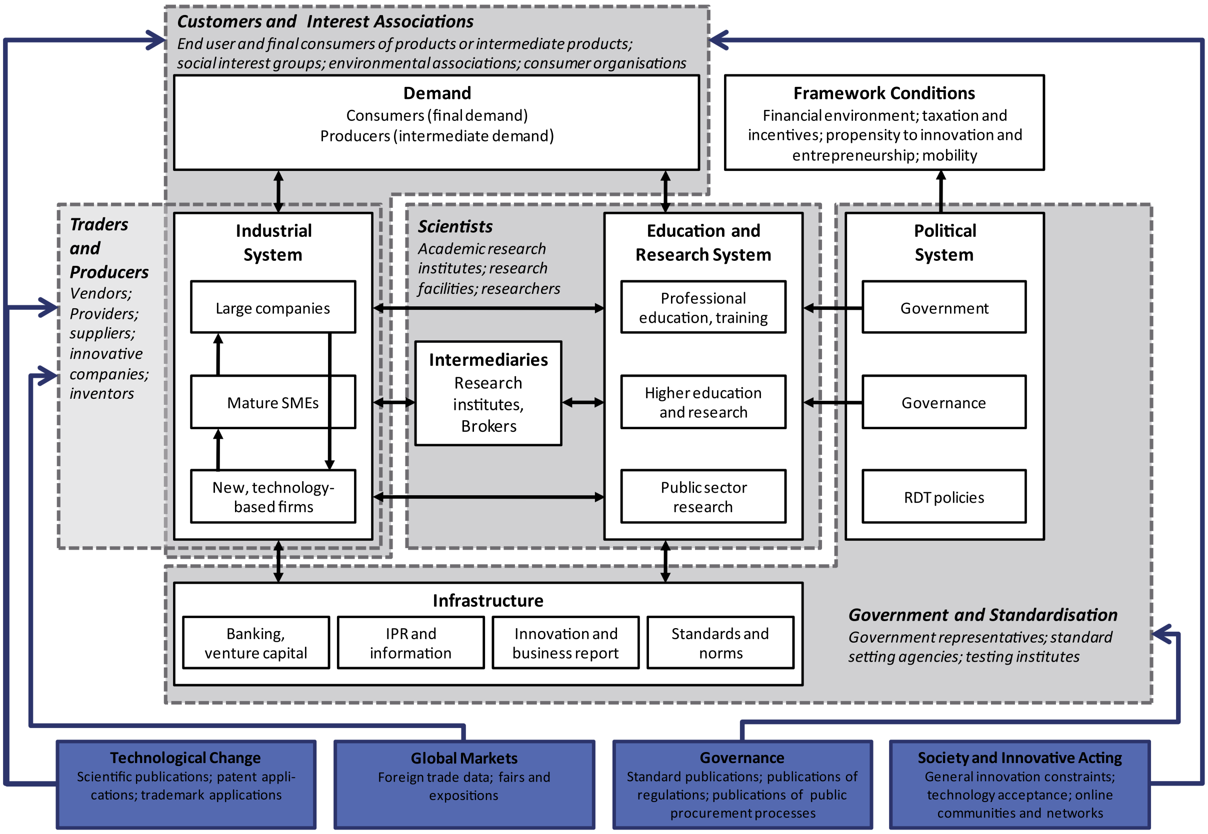

Fig. 4. National innovation system and the different stakeholder of standardisation with their indicators, modified according to [3].

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 [57–60]. However, other analyses can also be used at this point (see examples in section 2.1). For the remaining indicators of category 4, other studies and surveys were consulted.

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 [52,61], these fields also require an increased need of future standardisation work. In the following the exploratory results from the conducted surveys is to be discussed in a comparative analysis.

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 a comparison with the international development. For the final selection, experts of the national standardisation organisation in Germany (DIN) were involved. The following Table 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 2 shows 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, which 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 are very extensive, however bibliometric information in these databases offer opportunities to evaluate them effectively with the help of software support. Table 3 shows, for which indicators, panellists could be successfully 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.

To map the consensual nature of standardisation processes, at first two subsequent Delphi evaluation rounds have been conducted. For this purpose, corresponding standardisation topics had been previously 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 judgments in a second evaluation rounds. 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 an assessment of the panel expertise. Panellists were asked, according to the recommendation of [33], 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 Table 4). The statistical analysis of these ratings resulted in the prioritisation of relevant and urgent standardisation issues.

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 showed also no decrease of dispersion. For this purpose, the distances between the 3rd and 1st quantile 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

Table 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 Respective classification aggregated to sectors or scientific disciplines.
- Level 2 Aggregation according to the first or second level of the classification.
- Level 3 Aggregation according to the third or fourth level of the 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 for the Purpose of the Registration of Marks.
5. ICS = International Classification for Standards.
6. CPV = Common Procurement Vocabulary of the European Union.

standardisation activities. For this, the numbers of people, which give self ratings of their expertise but do not give estimation on the time priority of standardisation processes, were calculated:

$$n_{non-expert} = \left[n_{expertise} - n_{time}\right].$$

First evaluations of this number show that participants are more likely to complete the questions, which they can also 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 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
Panel composition according to the indicators (results of 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%

Table 5 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. To illustrate the different characteristics of the science and technology fields, Fig. 5 shows the average time period for the standardisation in the subject areas. Additionally, Table 6 in the appendix summarises all studied subjects in detail.

The subject fields 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 priority. 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 then 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 [49]. 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,

Table 4
Questions per topic (Delphi survey of 2009).

	Expertise on this topic				Time period for standardisation 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	○ ○ ○	○ ○ ○	○ ○ ○	○ ○ ○	○ ○ ○	□	□	□	□	□	□	□	□	□

Table 5
Key data of 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.

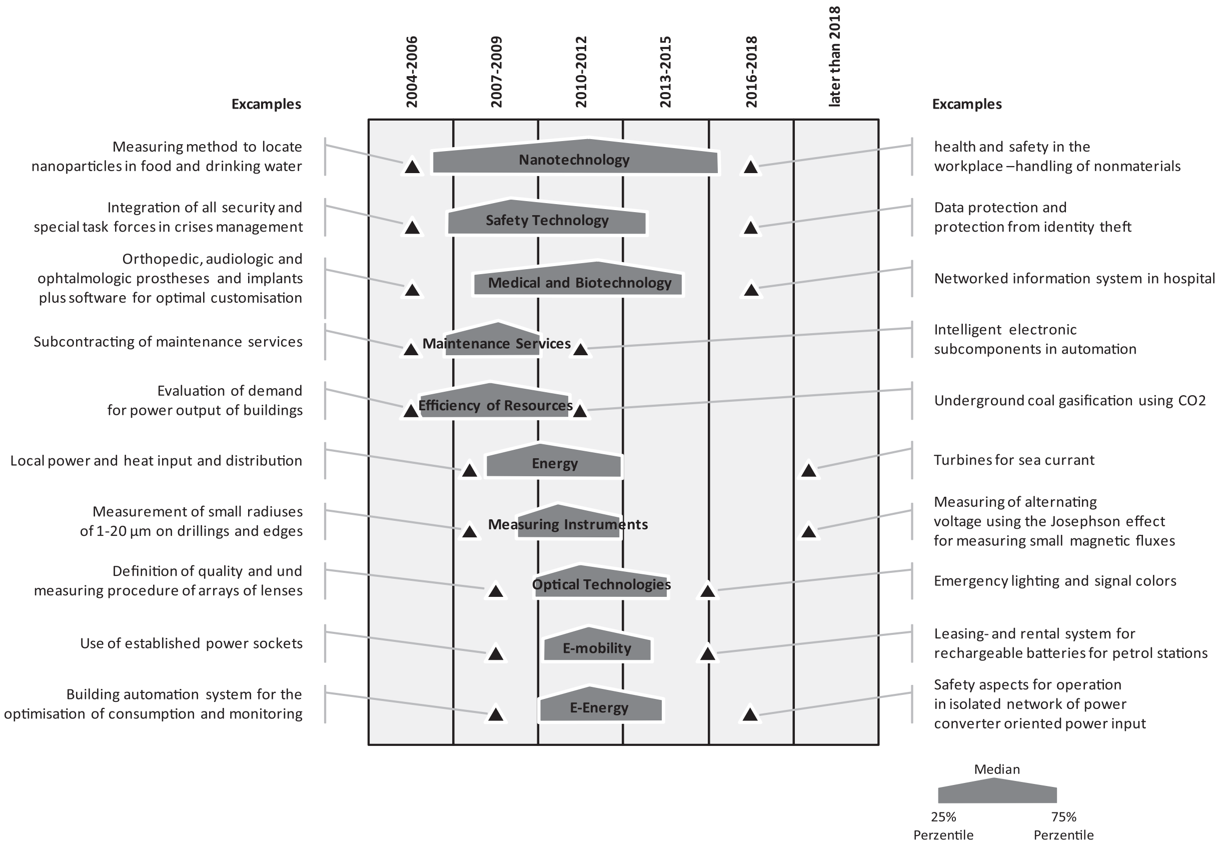

Fig. 5. Average time period for the standardisation in the different subject area.

especially standards for measurement and testing technology, as well as quality and safety standards are required. The latter become more relevant when risky, in our case nanotechnology products, are first introduced to the market [49]. 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 Medical 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 concerns in particular 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 Medical 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.

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 have 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 intransparent 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 all 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 on other application areas is not enough. The implementation will require some adjustments to the indicator set to ensure adequate foresight results.

Preceding qualitative survey rounds also offers the possibility to collect topics from the corresponding expert community, i.e. references on 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, an average of 14 to 48% of experts with high expertise could be identified. There are also a number of issues for which none of the identified stakeholders possessed technical expertise, even if these issues were a 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.

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. [62]. This approach 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. Especially network analyses provide similar scopes of application.

A closer look on 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 few and unsystematic foresight experiences regarding future priorities for regulations and standards could be identified [5]. 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 not only 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, he approach therefore relies on the hypothesis that panel members with high expertise give more correct first assessments compared to non-experts (see [24]). 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. 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 standardization 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 [6]. 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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Appendix A

Table 6
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, mobility, transport • 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

(continued on next page)

Table 6 (*continued*)

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, wastewater treatment, prevention, recycling and recycled • Materials and energy from waste • Industrial processes and product development • Households and marking of terminals • Water and wastewater 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-optimizing driver assistance systems • Safety and security components • Fuel cells
E-energy		
• Decentralization 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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