ETCETERA is an FP7 co-funded project
Contract No. 261512

EVALUATION OF CRITICAL AND EMERGING SECURITY TECHNOLOGIES FOR THE ELABORATION OF A STRATEGIC RESEARCH AGENDA

DELIVERABLE 4.3

Ideas for a novel method for emerging technology identification

Authors: Guido Huppertz (Fraunhofer INT), Beatrix Wepner (AIT)

November 2013

Dissemination Level: PU

Acknowledgement

The authors wish to acknowledge contributions from all Work Package 4 partners. The input from Dr. Olav Teichert (VDI-TZ) is especially acknowledged.

1 Introduction

The FP7 project ETCETERA aimed at identifying Critical and Emerging Technologies relevant to security in the European context. The results have led to recommendations for a European Security Research Agenda that deals with upcoming technological opportunities and threats, to alleviate the critical dependencies on technologies for member states and to provide alternative technological solutions. In Work Package 4 "Scanning for Emerging Technologies with Security Implications" emerging technologies were scanned for possible security implications in 10 to 20 years' time.

Different methods to identify emerging technologies were applied in a parallel fashion by three research institutions: Isdefe (Spain), AIT (Austria) and Fraunhofer INT (Germany). Two fundamentally different methodological approaches were employed in parallel: AIT used software based bibliometric and scientometric methods (bibliographic coupling and co-citation analysis), while Fraunhofer INT and Isdefe drew upon desk research methods with direct involvement of in-house and/or external technology experts.

A comparative analysis of the results of the three methods in Task 4.1 was performed and documented in Deliverable 4.2 of the ETCETERA project. Based on this comparative analysis, ideas were explored to derive a novel method for this kind of technology scanning, using the best features of the methods applied.

2 Identification and Priorisation of Emerging Technologies

2.1 General process

Details about the three methods applied by AIT, Isdefe and Fraunhofer INT as well as the WBAM method (Weighted Bit Assessment Method) are given in Working Document 4.1. Figure 1 illustrates the principal differences of the methods in a compact overview. In the following a short summary is given in order to make this report more comprehensive.

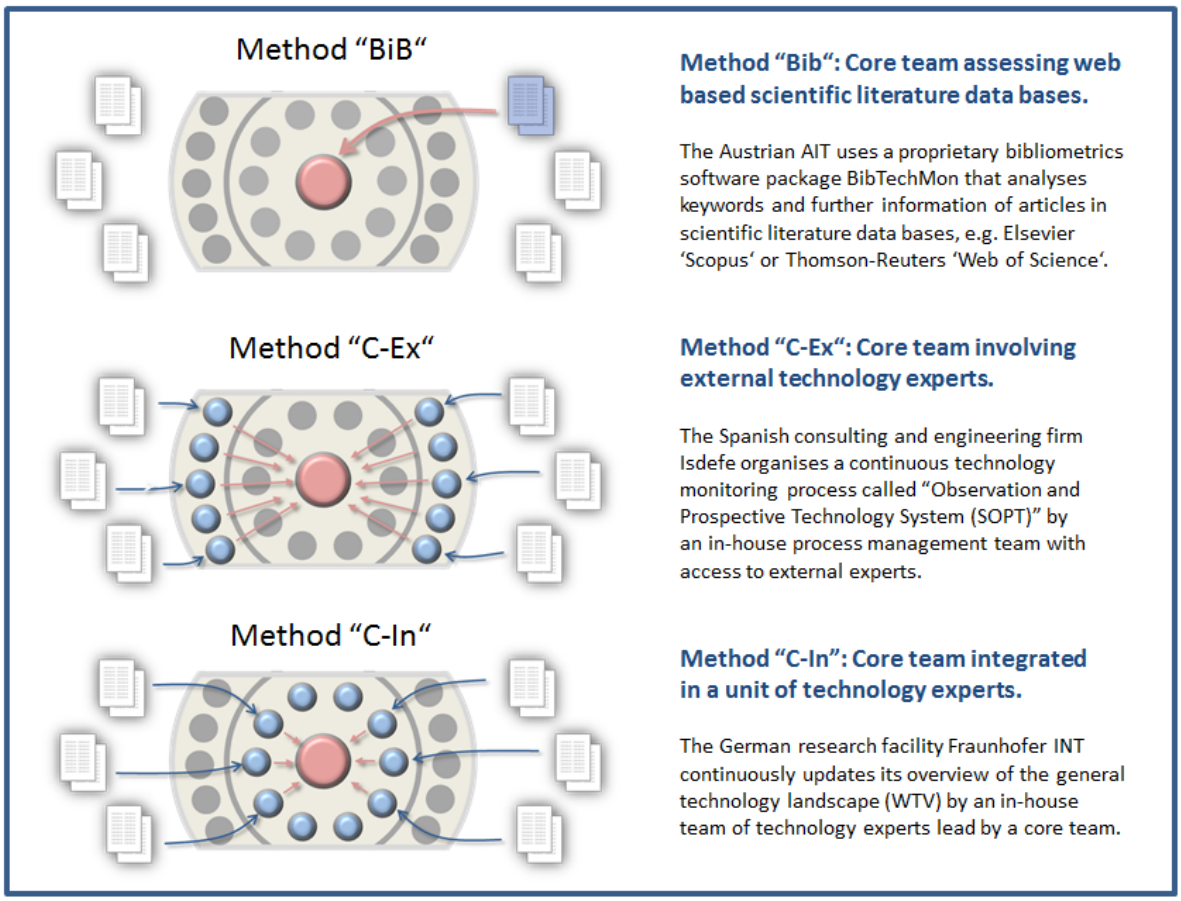

Figure 1: Schematic depiction of the technology scanning methods applied in ETCETERA.

The three methods for identification of emerging technologies were performed in parallel in Task 4.1. Their individual results were combined and assessed for different criteria using the WBAM method. Figure 1 oversimplifies the exact methodology in order to point out the characteristic features. For example AIT also used feedback from external experts to identify and assess technology themes. The method could therefore more precisely be described as "Core team with input from from external experts assessing web based scientific literature data bases". At Isdefe and Fraunhofer INT the core team members are at the same time to more or less extent involved as technology specialists. During the "search phase" all three partners gathered a list of emerging technologies that to their believe fulfilled given criteria, i.e. the emerging technologies should possibly lead to first security implications in between years 2020 to 2030. At the end of the search phase thus

three independent lists were available (Figure 2). The harmonization to combine the three individual lists to a common result made it necessary to cluster the technologies in thematical areas, since a decision on thematically overlapping technology nominations had to be done based on the content level. In a next step, this complete list needed to be validated with respect to the criterion, whether all technologies contained in it would match the prescribed requirements. Finally, the remaining validated technologies were prioritized with respect to the assessment regarding security relevance, time to market, application and market potential or ethical considerations.

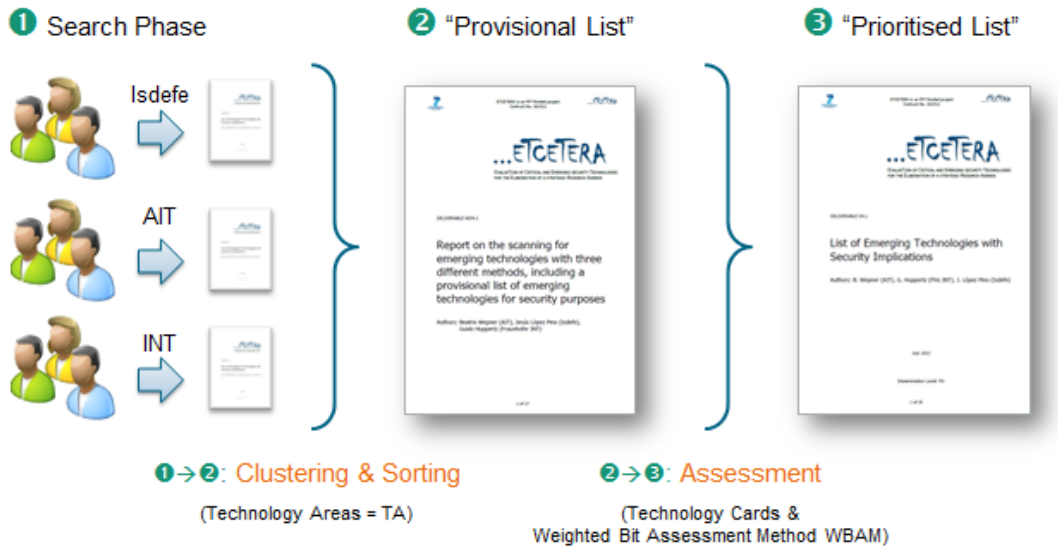

Figure 2: Chronology of identification process for emerging technologies used in ETCETERA.

2.2 Identification of Emerging Technologies

AIT used bibliographic coupling and co-citation analysis to identify critical and emerging technologies. These approaches are well established in bibliometrics and scientometrics by analyzing worldwide published literature. The software BibTechMon™ developed by AIT was used in this project to analyze data from publications derived from the Web of Science. BibTechMon™ is a science mapping tool based on co-object analysis. The tool supports the import of data, the relational analysis, the visualization and the assessment of identified research issues by interactive graphical retrieval of relevant publications. In case of co-citation analysis it draws knowledge bases as maps motivated by geography. The above mentioned co-citation analysis leads to good results in identifying topics, their roots and interdisciplinary links in a considered field. Topics appearing on the science maps were identified, labeled and the publications of each cluster screened for emerging technologies if they were not obvious in the title in cooperation with security experts.

The methodology developed by **Isdefe** for the identification of emerging technologies is based on its pool of engineers, devoted full-time to technology watch and foresight activities. This group of experts has a deep knowledge in different technological areas, such as ICT, CBRN protection, optronics, etc. They have taken part in several national and international projects related to the identification of technologies.

To identify emerging technologies, two complementary approaches have been used: A top-down approach whose starting point is security and R&T strategies, identifying future needs where technology can be applied (What technologies are embedded in the systems? Which of them are key for the system performance? etc.), and a bottom-up approach, starting from the universe of technologies, where only those technologies not mature enough have been selected, using the Technology Readiness Level (TRL) scale.
The main sources of information have been, on the one hand, open studies related to national MOD technology strategies for the medium and long term, NATO/RTO activities, EDA CapTechs activities in the security environment, and results and reports from European Commission programs about technology and security as well as different databases, results of technology foresight and trend analysis, relationships and partner ships with the scientific and technological community, patent search, etc. The outputs of this searching process were analyzed by experts in the relevant area of technology in order to create added value, oriented to the objectives of this study.

At **Fraunhofer INT** the department "Technology Analysis and Foresight (TAV)" was responsible for systematic observation of technology developments concentrating on technologies with aspects for security issues and applications. An in-house team of scientists with different expertise (natural scientists and engineers) continuously performs desk research in order to perceive any technological development that is relevant for the tasks or objectives of the department. The foresight process involves (meta-) scanning or monitoring using different sources like scientific journals, magazines, specialist literature or grey literature, participation in conferences, workshops and the like and conducting of expert interviews, attendance of industrial fairs, competitive exhibitions or presentations. Should a qualitative (e.g. special technology area without expertise of a team member) or quantitative (e.g. problem description with deep specialization beyond in-house capability) thematic gap be identified, external experts either inside or outside the Fraunhofer-Gesellschaft are consulted.

The results of all three methods were merged into a "provisional list" of emerging technologies for prioritization by experts using the **Weighted Bit Assessment Method (WBAM)**.

2.3 Priorisation of Emerging Technologies

Fraunhofer INT has developed the **Weighted Bit Assessment Method (WBAM)** as a tool to gather information from a variety of sources into a simple matrix. The WBAM is mainly devised to serve as an easily understandable planning support tool that enables interaction between stakeholders of different backgrounds.
In the original WBAM for the evaluation of toxic chemicals as to their availability, deployability, toxicology, and the possible socioeconomic consequences of their release, a binary system was applied (yes = 1, no = 0).

In contrast to this original approach, in ETCETERA the WBAM value range of weighting factors comprised [-1, 0, 1, 2]. For each entry in the "provisional list" (see above, section 2.1) technology experts of the partners AIT, Isdefe and Fraunhofer INT were asked to tick appropriate boxes in the following five categories:

- the relevance for security issues ("Security Relevance"),
- the time until implications for security issues will occur ("Time frame"),
- the potential for usage in security related applications ("Application Potential"),
- the potential they could have to be commercial successful ("Market Potential"),
- and possible implications concerning ethical aspects ("Ethical Consideration").

The answers of the experts were gathered and accumulated to a Technology Rating TR for each category according to the scheme

$$TR_{category} = [Answer \times WF]_{Expert1} + [Answer \times WF]_{Expert2} + [Answer \times WF]_{Expert3}$$

with "answer" being "x" or " " [for "yes" or "no"] and WF being the individual weighting factors. Whereas generally three expert opinions were gathered per technology, in some cases only two votings existed. In these cases the respective TR was calculated by scaling both expert ratings with factor 3/2 in order to compare all results on the basis of the same input magnitude. For the categories "Security Relevance" and "Application Potential", only the first aspect of the twofold questions was considered: "How do you rate the impact this technology could have on future security issues?" respectively "Does this technology offer significant benefits for security agencies and the protection of society?"
Using the accumulated ratings, a ranking of technologies was achieved and the most relevant technologies were easily identified resulting in a prioritized list of emerging technologies. Figure 3 shows a screenshot of the accumulated results of ETCETERA WP4 WBAM questionnaire for some entries in area "communication technology".

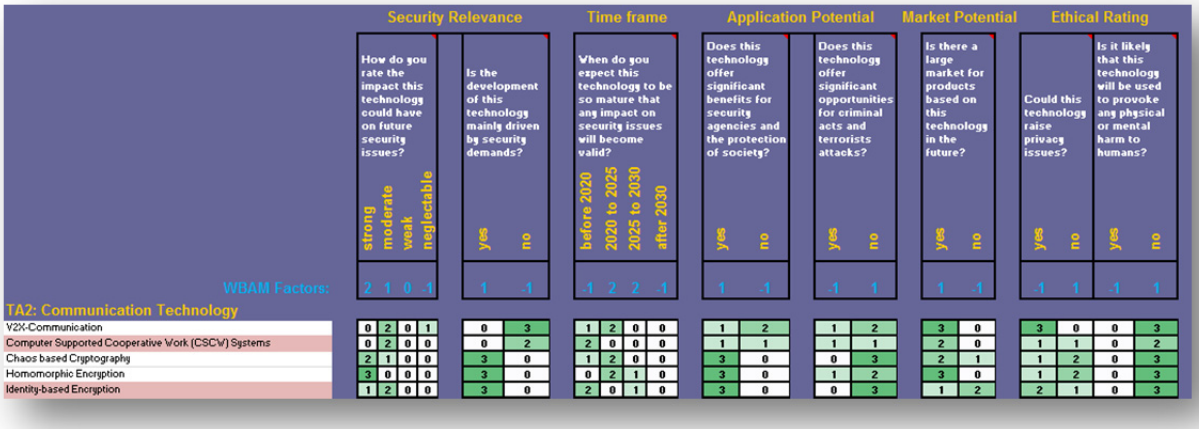

Figure 3: Structure of the WBAM questionnaire used for the assessment of technologies contained in the "provisional list". [Source: Fraunhofer INT]

In figure 4 one possible realization of the prioritized list is shown, based on the primary sorting criterion "Security Relevance" and the secondary sorting criterion "Market". In technology area "Biometrics" all three entries from the provisional list were excluded because of the concordant classification as coming "before 2020" in category "time frame".

	TA1: Biometrics	SecRel	Time	Market	Appl	Ethics
	TA2: Communication Technology	SecRel	Time	Market	Appl	Ethics
1	Homomorphic Encryption	6	6	3	3	4
2	Post-Quantum Cryptography	6	1.5	3	3	3
3	Quantum Cryptography	6	3	-1	3	2
4	Chaos based Cryptography	5	3	1	3	4
5	Identity-based Encryption	4	0	-1	3	2
6	Clean-Slate Future Internet	3	0	-1	1	4
7	Artificial Immune Systems	2	3	1	1	4
8	V2X-Communication	1	3	3	-1	0
9	Cognitive Radio	1	3	-1	-1	6

Figure 4: Prioritized list of technologies for two technology areas, sorted according to parameter Security Relevance (1st criterion) and Market (2nd criterion). [Source: Fraunhofer INT]

2.4 Strengths and weaknesses of the methods applied

2.4.1 Technology Identification Methods

During the execution of Task 4.1 some general problems appeared that were not related to a specific method. They comprised the general understanding of the term "security" and the meaning of "implication of a technology for security". Furthermore, the question whether an emerging technology fulfills the target time frame can be interpreted differently, e.g. by using the criterion "any technology that with high certainty leads to applications in years 2020 to 2030" is included, or in contrast to that to accept "any technology for which one cannot exclude that it will lead to first applications in years 2020 to 2030". Also there is a general problem related to the question "what is a single technology" and "what is a technology complex" or a "group of different technologies"? In some cases this may cause complications to rate the application readiness of a technology that depends on e.g. progress of enabling technologies, making it difficult to judge whether or not a technology fulfills a targeted time frame.

The following paragraphs concentrate on those strengths and weaknesses that are of specific relevance for the methods applied.

Software based bibliometric method - AIT

Strengths

- Quantitative description and assessment of research activities
  - Bibliometry delivers a broad overview in extremely short time: one can scan thousands of publications within seconds.
  - Quantitative assessment of publication activity in a technology domain allows for
    - **Analysis of time relations** of the identified emerging technology topics, e.g.
      - Identification of emerging topics by portfolio analysis, making an increase in publications of technological (**technology push**) or demand based developments **(demand pull)** over the years visible.
    - Identification of **geographical distribution** of research activities
    - Identification of **networks of cooperation**

- Detection of developments in areas outside monitoring focus
  - Since Bibliometry scans very fast there is no need to confine the search area in a data base to narrow interest fields, as a human expert would probably have to do due to time or efficiency constraints.

- Quantitative visualization of contents, structure and connections of security related research and technology fields (based on quantitative data)
  - This is a very valuable feature of bibliometry. For example, technology foresight can help to identify research partners (e.g. in civil protection or public health sector, research institutions) as well as possible competitors. Competitiveness is a major driver in technology foresight, e.g. concerning national or union wide economy (competition with other economies), industry (competition with business rival) or forces (against a potential opponent). The visualization of research networks or hot spots in certain topics is very useful in this context.

Weaknesses

- Limitation in assessment of publication content: bibliometrics is limited to the evaluation of keywords or abstracts, not the content of the complete text.
- General search terms like "security" lead to vast amounts of data: therefore in Task 4.1 only the most relevant articles of years 2006 and 2010 could be evaluated and compared.
- Generic definition of the search term "security" causes some non-specific results with unclear implication for technology related security issues (e.g. "Effective water resources management")

Expert based desk research method – Isdefe and Fraunhofer INT

Strengths

- Assessment of technology meaning and relevance
  - Selective and science-based scanning and identification of specific and security related (emerging) technologies in different development status
- Early recognition of developments in monitored areas
  - Identification of "weak signals" of emerging technology developments through experts which are engaged permanently to (one or multiple) specific technology areas with a well-founded insight in their thematic areas
- Assessment of future development resp. time horizon
  - Assessment of the meaning of a technological development (disruptive potential) through insight in existing technological hurdles in the respective or an involved domain
  - including the respective pace of progress and technological interdependencies

Weaknesses

- Human experts can develop a bias or concentrate on specific themes of interest over time, maybe neglecting or missing some relevant development in another field.
- Technology monitoring by human experts must be executed as a continuous task in order to detect trends.

2.4.2 Technology Assessment Method

For validation and prioritisation of the identified technologies the weighted bit assessment method WBAM was used. Advantages to use WBAM for this purpose are:

- low ambiguity because of limited choices or even binary character
- delivers results even in situations with polarized opinions about a technology
- no inducement of personal assessment by mainstreaming effect in groups
- weighting factors can be used to emphasize technologies with preferred properties
- assessment of different experts can be perfectly compared – easy assessment of consensus or disagreement concerning technology properties

Limitations of WBAM in this context are:

- expertness of people who rate technologies can remain unclear (depending on the specific selection process of experts)
- reduced possibility to differentiate between different technologies (depending on the number of possible choices for a property)

The formulation of appropriate WBAM questions is a challenging task, while the filling of the matrix is relatively straight-forward. As the WBAM derives sorted lists of entries from the information in the matrix by simple multiplication and addition operations the use of this method can be learned and understood within some minutes. As basic functionalities of spread sheet programs are used as technical background for the matrix, the further exploitation of the gathered data for analysis or compilation of 2D-charts is very easy, too.

Neither the number of expert votes in total nor the WBAM procedure itself is sufficient to claim a complete unbiased and impartial evaluation of the applied technology scanning methods. But in order to derive conclusions about weaknesses and strengths of the applied scanning methods the usage of the WBAM results seems a feasible basis for an open minded assessment.

2.5 Conclusions drawn for a novel method

Today, computers can only insufficiently analyse knowledge generated by humans. Since an extrapolation of present status quo or development in a certain technological field to derive statements about future possibilities and possible futures needs requires to some extent phantasy or creativity and experience in technology foresight, today's computer algorithms cannot replace human expert assessment. Therefore it is necessary to integrate technology experts in at least one or two steps of a future-oriented technology identification task. The comparison of the three scanning methods in ETCETERA Deliverable 4.2 revealed that the specific strength of human experts is the assessment of the future development of an emerging technology.

However, especially the application field "Security" is a very wide topic. Technologies used here are from various fields, so a great range of experts is needed. And even inside a certain technology field – if a precise frame of such a field can be confined at all – it is questionable, whether even an experienced technician can claim to cover all relevant current developments in that field. In contrast to that computer based assessment of scientific data resources is a non-directional search, not influenced by any bias arising from previous experiences. As such bibliometric analysis is a strong tool to erase or avoid blind spots and to safeguard the completeness of the assessment of a technological development, including identification of new research fields and relevant experts within those fields, being limited only by the defined search strategy.

In conclusion, computer based identification of topics is a good basis and amendment however participation of human experts is indispensable and cannot be displaced. The methodical strengths of the three applied approaches can be characterized as follows:

Desk Research (Isdefe, Fraunhofer INT)

- Early recognition of developments in monitored areas
- Assessment of technology meaning and relevance
- Assessment of future development respectively time horizon (Forecast)

Bibliometrics (AIT)

- Delivers a widespread and objective overview on a topic (Backcast)
- Detection of developments in areas outside monitoring focus
- Quantitative description and visualization of research activities (geographical, temporal)

In consequence, to combine the strengths of the applied scanning approaches it is proposed to weave them together, e.g. in a three step modus using bibliometric analysis for a widespread overview on main topics, then assigning experts in the relevant areas for a detailed desk top research based on the foregoing results, and finally confirming the findings by a focused bibliometric analysis with more precise and concrete search terms. For the validation and prioritisation of technologies identified by the foregoing procedure the WBAM method proved to be a very useful and efficient tool. This approach is described in the following section.

3 Ideas for a novel method

The term "method" in this context refers to the application resp. combination of known foresight procedures in a specific manner. It thus defines a process scheme and is not meant in the sense of the invention of a new particular foresight technique.

The experiences of ETCETERA Work Package 4 lead to our following recommendation for a 3-step approach to identify emerging technologies:

- **Step 1: "Search Phase"**

  Collection and bibliometric analysis of scientific literature (based on pre-defined search query)

  - *Delivers a widespread and unbiased overview on a topic (**Backcast**)*
  - *Identifies emerging research „hot spots" and visualizes their interaction*

- **Step 2: "Analysis Phase"**

  Assessment of material by technology foresight specialists in respective technology domains (Desk Research)

  - *Identification of relevant developments in a technology area*
  - *Analysis on application potential, complementary and concurrent developments*
  - *Assessment of the future development (**Forecast**)*
  - *Deduction of recommendations for specific stakeholders*

- **Step 3: "Validation Phase"**

  Bibliometry (based on refined search query) and WBAM for affirmation of results

  - Bibliometry:
    - *Affirmation of completeness regarding publications, researchers, institutes*
    - *Complement to the assessment of thematic experts regarding the current status (past to present) of the temporal development (**retrospective affirmation**)*
    - *Generation of charts to visualize intensity of cooperation between research groups and the temporal development or dynamics of a topic, universally or clustered with respect to certain groups, nations etc.*
  - WBAM:
    - *Affirmation of assessment (core statements) by additional thematic experts (internal/external) regarding the future development of the given topic (**prospective affirmation**)*

The procedure suggested is a combination of well-proven desk research, performed by experienced technology specialists, and the use of current state-of-the-art computer based knowledge extraction from scientific texts.

Currently, in desk research a technology specialist tries to summarize all relevant aspects with respect to a technological topic. "Relevant" here means those aspects the specialist knows and values of importance. This implies the question of completeness of the respective expert's knowledge at the time of the analysis and the reliability of his assessment.

Both aspects – completeness and reliability – are addressed by use of bibliometry. Even a well experienced expert needs to invest some time to reassure himself that he has not missed some new or unusual relevant development in a technological domain. The higher the demand concerning the reliability of an assessment, the higher are the efforts concerning the validation of the results. By use of a bibliometric survey in a relatively short time a comprehensive map of research activities in a technological domain can be generated. This can support the expert by confirming his prior expectations or even add to his knowledge ensuring the expert does not to miss out relevant developments. Although bibliometry is also limited concerning the completeness of the coverage of a domain it can substantially cut down the efforts for validation of a result. Moreover, if the bibliometric survey supports the expert's assessment concerning relevant research groups and developments, the reliability of the desk research result is substantially raised. Another aspect – not to be underestimated – is the simple fact that a bibliometric survey can greatly help for a traceable documentation of a performed task, in order to illustrate to a client the research activity in a domain on the one hand, and the literature sources used for the task on the other.
Since in a technology identification or analysis task the list of relevant keywords presumably will be adjusted during the process a post-analysis bibliometric survey is advisable. Whereas the bibliometric survey in the first process step primarily serves to deliver an unbiased and comprehensive data base concerning literature and research activities for further discussion and input, in the third step the use is to affirm the findings of the desk research analysis under consideration of a refined search query, to illustrate the evolution of a technological development and to characterize the main actors in research, e.g. with respect to geographical location or nationality.

While a bibliometric survey is well suited to evaluate scientific publication activities from past to present, the future expectation concerning a technological development must be based on human experts. In order to affirm the technology assessment of a small group or even a single expert, expert interviews or other participative inclusion of additional expert opinions are common practice. The weighted bit assessment method WBAM proved to be a very efficient and easy to handle tool in that context. Since prospective statements to some extent are of speculative nature it is prerequisite to consult a sufficient number of specialists with proven or reasonable expertise.

In practice, this 3-step approach might be exercised in several internal cycles, especially between steps 1 and 2 with respect to the elaboration of relevant keywords during technology assessment and the modified bibliometric result when adjusting the search query based on those keywords.

The task to identify emerging technologies not simply comprises to generate a list with formerly unknown technologies. It is about

- finding new developments (also in long known but stagnating technological domains),
- validating the technologies found with respect to prescribed necessary criteria and
- prioritizing the technologies found with respect to given desired criteria.

It is the belief of the authors that the described 3-step process will deliver sophisticated results for that purpose with at the same time reasonable effort.

4 References

Price, D. J. S. (1965) Networks of scientific papers. Science, 149: 510-515

Hörlesberger, M., Wagner-Luptacik, P. (2010) Authorities, Hubs, and Brokers in Communities of Practices. Creating and Managing a Technology, World Scientific, 381 – 399, ISBN: 978-981-4313-38-4

Kopcsa A, Schiebel E. (1998). Science and Technology Mapping: A New Iteration Model for Representing Multidimensional Relationships. Journal of the American Society for Information Science (JASIS), 49 (1): 7-17

Shibata, N., Kajikawa, Y., Takeda, Y. and Matsushima, K. (2009) Comparative study on methods of detecting research fronts using different types of citation. Journal of the American Society for Information Science and Technology, 60: 571–580

Schiebel, E. (2012) Visualization of Research Fronts and Knowledge Bases by Three-Dimensional Areal Densities of Bibliographically Coupled Publications and Co-Citations. Special Issue Scientometrics, 91: 557-566, DOI: 10.1007/s11192-012-0626-8

J. Burbiel, N. Engelhard, S. Grigoleit, H. John, J. Schulze, Gefahrenpotentiale von chemischen Kampfstoffen und toxischen Industriechemikalien - das Punktesystem, Bundesamt für Bevölkerungsschutz und Katastrophenhilfe -BBK-, Bonn: Gefahren und Warnung - Drei Beiträge. Rheinbreitbach: MedienHaus Plump, 27-58 (2009)