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Technology Evaluation and Assessment of its Impact

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Graz, January 2017

Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to TUGRAZonline is identical to the present master‘s thesis dissertation.

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Date Signature

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Abstract

The generation of innovations based on new technologies has always been an important factor for commercial success. To get along with the increase of sophisticated and dynamic market requirements, it is essential to strengthen and to ensure the competitiveness with novel innovations. Therefore, an increasing need for technology assessment tools can be recognized to identify potential technologies as prospective market leaders out of a mass. As an investor it is important to have a certain amount of risk willingness, nonetheless economic aspects have to be always taken in consideration. That is why an evaluation regarding technology maturity, market attractiveness and competitor situation is indispensable.

The main problem from the perspective of a potential investor is to evaluate if there is just a hype about a technology which is not profitable, or if a technology is really novel and could earn profit in the future. Thus, the development of a versatile assessment concept is the aim of this thesis.

The master thesis is structured into the parts of literature research, assessment tools analysis and final the development of an iterative assessment process to prioritize technologies. The objective of the literature research is to gather technology assessment tools as well as assessment approaches to conduct an analysis on how applicable they are. Based on this analysis, an assessment process is proposed which should be less time consuming and resource saving compared to the analyzed ones. Therefore, this process is divided into three steps to reduce successively the number of technologies with less or without potential. In step 1 of the assessment process, relevant technologies are sorted on defined evaluation criteria. Afterwards, pre-sorted technologies are chosen and a portfolio analysis based on technology attractiveness and market attractiveness criteria is conducted. As a last point, the remaining technologies with a high potential need to go through a competitive analysis. In this third step, gathered assessment tools from literature research can also be used for an informed technology prioritization.

With the aid of this assessment process, prospective technology trends should be estimated properly and the risk of false investment decreased. Only extraordinary technologies with high potential of success will disrupt the market with their uniqueness.

Kurzfassung

Das Generieren von Innovationen basierend auf neuen Technologien stellte schon immer einen zentralen Treiber für den unternehmerischen Erfolg dar. Um den immer komplexeren und dynamischeren Marktanforderungen gerecht zu werden, ist es erforderlich mit revolutionären Innovationen die unternehmerische Wettbewerbsfähigkeit zu stärken und zu sichern. Dabei besteht ein zunehmender Bedarf an Technologiebewertungsmethoden, um aus der Masse der potenziellen Technologien, Trends für zukünftige technologische Marktführer zu bestimmen. Als Investor ist es daher wichtig, ein gewisses Maß an Risikobereitschaft zu besitzen, jedoch dürfen dabei aber ökonomische Aspekte nicht aus dem Auge verloren werden. Eine wirtschaftliche Beurteilung hinsichtlich der Marktattraktivität, der Technologiereife und der Wettbewerbssituation ist damit unerlässlich.

Die zentrale Problemstellung eines potenziellen Investors oder Unternehmens besteht nun darin zu beurteilen, ob es sich möglicherweise nur um einen kurzen Hype einer Technologie handelt der wirtschaftlich nicht rentabel ist, oder ob doch eine revolutionäre Technologie in Entstehung vorliegt mit der in Zukunft Gewinnmargen erzielt werden können. Die Entwicklung eines vielseitig einsetzbaren Bewertungskonzeptes wird im Rahmen dieser Masterarbeit durchgeführt.

Der Aufbau der Masterarbeit gliedert sich dabei in die Punkte Literaturrecherche, Methodenanalyse und letztendlich der iterativen Erarbeitung eines Bewertungsprozesses zur Priorisierung unterschiedlicher Technologien. In der Literaturrecherche werden Technologiebewertungsmethoden sowie empfohlene Bewertungskonzepte gesammelt und anschließend in Bezug auf deren Anwendungstauglichkeit analysiert. Davon ausgehend wird in der Folge ein Bewertungsprozess erarbeitet, der zeit- und ressourcenschonend Anwendung finden soll. Dieser Prozess wird dafür in drei Stufen ausgeführt um sukzessive die Anzahl der potenziellen Technologien einzuschränken. Im Schritt 1 werden relevante Technologien betreffend unterschiedlichster definierter Kriterien sortiert. Anschließend werden im Schritt 2 vorsortierte Technologien ausgewählt und einer vorläufigen Analyse bezüglich Technologieattraktivität und Marktattraktivität unterzogen. Im abschließenden Schritt 3 kommt es zu einer Wettbewerbsanalyse der verbleibenden Technologien. In diesem Schritt können auch zusätzlich gesammelte Technologiebewertungsmethoden aus der Literatur für eine fundierte Technologie Priorisierung herangezogen werden.

Anhand dieses Bewertungsprozesses sollen somit in Zukunft Technologietrends richtig eingeschätzt werden können und dadurch das Risiko für Fehlinvestitionen minimiert werden. Denn nur außergewöhnliche Technologien mit hohem Erfolgspotenzial werden durch ihre Einzigartigkeit den Markt revolutionieren.

Table of Content

1 Introduction

Innovations are and will always be an important factor for a firms' business success. They help to deal with the increase of sophisticated and dynamic market requirements and hence aids to strengthen the core competencies of the enterprise. As a consequence, an increasing need for technology assessment tools is recognizable to identify potential technologies out of a mass as future market leaders.

Due to the global competitive marketplace, technology assessment (TA) gets always more important to enterprises to compete with their products on the market and to earn profit for keeping their business alive[1]. Although investors and enterprises have to show a certain amount of risk willingness for investing in promising technology developments and adoptions, TA is a key part for their decision making.

Objectives of technology assessment can be in determining:[2]

- Research and development (R&D) direction
- New technology adaption
- Incremental improvements in existing technologies
- Level of technology friendliness
- Make-or-buy decisions
- Optimal expenditure of capital equipment funds
- Market diversification

Moreover, TA help enterprises to:[3]

- Perform a value chain analysis
- Identify market advantages
- Avoid being preempted in the marketplace
- Stay on the cutting edge
- Define the cutting edge
- Maximize the use of information and minimize product makespan
- Achieve a competitive advantage in terms of costs, quality or time to market

The following subchapters deal with the objectives of the research and which research limitations are set. Furthermore, the definition of a technology is discussed and a corresponding life cycle is explained in detail. The chapter ends with an overview about the structure of the ongoing thesis.

[1] Cf. Henriksen (1997), p.617
[2] Cf. Henriksen (1997), p.616
[3] ibidem

1.1 Objectives

Based on the problems mentioned in the introduction chapter, the objective of this thesis is to develop an assessment approach for an investor, which allows to sort and filter technologies in an effective way to find technologies with a high potential for being economically successful. Additionally, this approach should be built on quantitative methods, but should include qualitative methods as well. Also, the time issue for making an informed choice in a less time consuming manner has to be taken in consideration.

Besides achieving the development of an approach for assessing successful technologies, this thesis should serve as data base for gathered assessment methods and recommended literature approaches.

1.2 Technology Definition

It is important to be clear about the definition and differentiation between a technology and a technique, since these words are often used in the same way. Whereas a technology only means know-how for solving a problem, a technique is a final product which can implement a few technologies (see Figure 1). For the differentiation and to get an insight of how both terms are used, the system approach by Bullinger serves as aid by dividing the terms into knowledge base (INPUT, which is technology), in solving a problem (the actual solving PROCESS) and in a solved problem (OUTPUT, which is a technique).[4]

Technology

The term technology is used to describe scientific-oriented, technical coherences, insofar it can be applied for solving technical problems. Therefore, technology means the knowledge to solve technical problems and correspond to the know-how term (INPUT).[5]

Applied Research, Development, Engineering, Strategy

The usage of technologies within the frame of R&D processes is construed as its own category and include task-based fields like applied research, development, engineering and strategy (PROCESS).[6]

[4] Cf. Bullinger (1994), p.33-34
[5] ibidem
[6] ibidem

Technique

In contrast to the technology explanation, the term technique is used to describe tangible results out of the problem solving process, their production and their application (OUTPUT).[7]

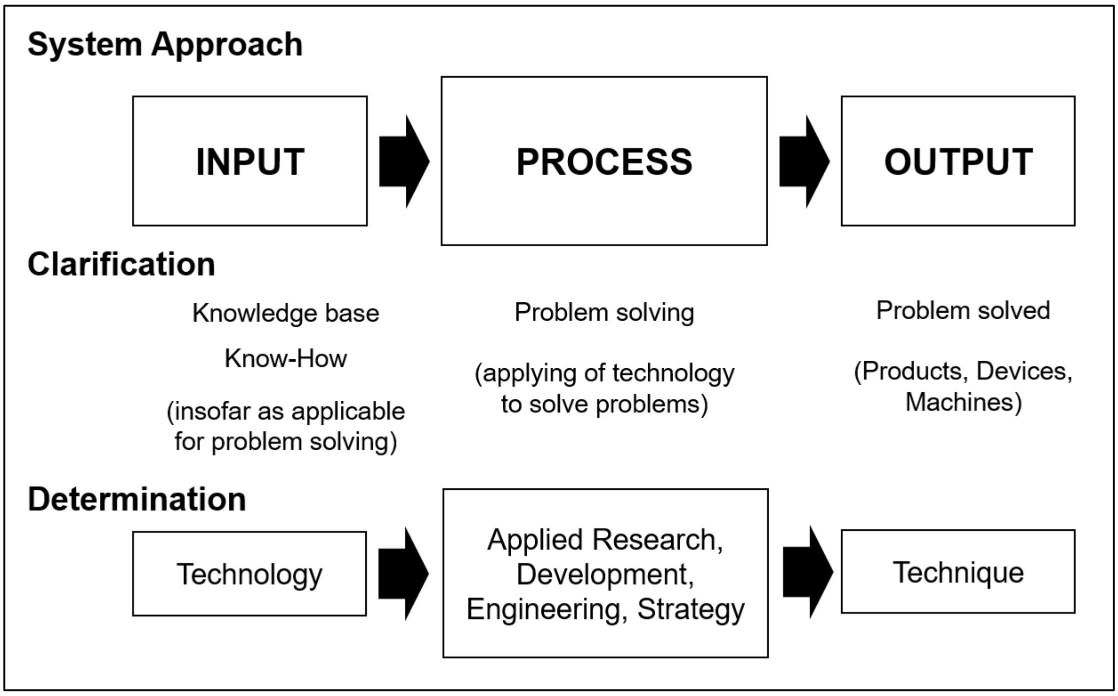


Figure 1: Definition technology and technique[8]

1.3 Technology Life Cycle

With the aid of technology life-cycle models, typical ideal development processes of technologies are recorded. The development stage of a technology allows to derive strategic actions and to evaluate the potential of a technology. Hence, technological competences can be built or dismantled on time.[9]

Figure 2 illustrates the development of the performance of a technology, which is based on the s-curve concept of McKinsey & Company[10]. Technologies are categorized in pacesetter, key, basic and replaced technologies with their corresponding phase

[7] Cf. Bullinger (1994), p.34
[8] ibidem
[9] Cf. Schuh et al. (2011), p.37
[10] Cf. Schuh et al. (2011), p.43

indicator for development, growth, maturity and age. Through the categorization, strategic actions can be derived for each phase.[11]

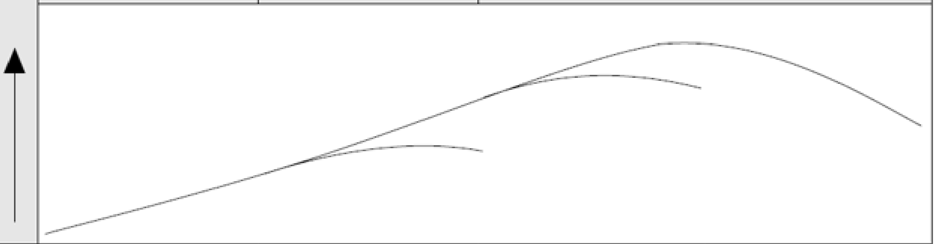
	Pacesetter	Key	Basic/Replaced Technologies	
Degree of use of competitive potential				
Indicators	***Development***	***Growth***	***Maturity***	***Age***
Uncertainty of technological performance	High	Medium	Low	Very low
Investment in technological development	Low	Maximum	Low	Insignificant
Extent of potential applications	Unknown	Large	Established	Decreasing
Type of development	Scientific	Applied	Applied	Cost-oriented
Impact on cost-performance relation of products	Secondary	Maximum	Marginal	Marginal
Number of patents	Increasing	High	Decreasing	Low
Type of patents	Concept patents	Product patents	Process patents	Process patents
Entry barriers	Scientific capability	Workforce	Licences	Know-how
Availability	Very limited	Restructuring	Market-oriented	High

Figure 2: Life-cycle phases and strategic relevance of technologies[12]

A disadvantage of the life-cycle analysis is the dependency of a technology and its application. It could be the case that a technology with its application (technique 1) has already reached the aging phase of a life-cycle, but the same technology with another application (technique 2) could be just in the development phase.[13]

[11] Cf. Schimpf (2010), p.210
[12] Schimpf (2010), p.210-211
[13] Cf. Schimpf (2010), p.210

Pacesetter technologies

They are expected to have a high effect on market potentials and competition dynamics in the future. These technologies are still in their development stage, but it is recognizable that they will influence as of their potential the competition. These technologies are the basis for future key technologies.[14]

Key technologies

Evolved from pacing technologies, key technologies have the highest competitive-strategic relevance. They have significant influence to the current branch competition and are an inherent part of the branch technology spectrum, but not yet available for all competitors. The growth stage belongs to these technologies and they are the initial position for base technologies.[15]

Base technologies

Based on the high diffusion and large availability of the knowledge of these technologies, they cannot be used for a competing differentiation anymore since their competition potential is exhausted. However, control of these technologies are necessary for a serious competition.[16]

Replaced technologies

These technologies are or will be substituted through other technologies. They reached the age stage within the life cycle.

1.4 Research Limitations

This thesis deals only with methods, tools and approaches for assessing technologies. Screening concepts and methods as well as proposed data sources for finding innovative technologies are not part of this thesis.

For conducting the assessment study, around 100 technologies are already available at the Institute of Innovation and Industrial Management (IIM) in form of a catalog. This technology catalog (see Figure 3) serves as input for the later following assessment approach in chapter 4. The technology catalog is structured into the fields of the overall

[14] Cf. Bullinger (1994), p.96
[15] Cf. Bullinger (1994), p.97
[16] ibidem

technology category, the technology itself, the current technology application (technique), the data source with the corresponding uniform resource locator (URL) and the publication year of the technology. The whole catalog with all technologies can be found in Appendix A.

Assessment

Technology Catalog

Category	Technology	Application	Source	Publication Year	URL/Abstract
Energy Generation	low-head-hydro-power	gorlov-turbine	Science Direct	2014	Theoretical and conditional monitoring of a small three-bladed vertical-axis micro hydro turbine
Construction	3d-printing	on site 3d-printing of houses	Interesting Engineering	2016	http://interestingengineering.com/3d-printed-office-is-the-office-of-the-future/
Nano Technology	nano crystal catalyst	H2 production	Interesting Engineering	2016	http://interestingengineering.com/splitting-water-using-tiny-nanowires/
Nano Technology	nano transistors	micro CPU	Interesting Engineering	2016	http://interestingengineering.com/berkeley-makes-smallest-transistor-ever/
Mobility	hydrogen fuel-cell	e-airplane	Interesting Engineering	2016	http://interestingengineering.com/accelerating-the-future-of-aircraft-with-electricity/
Mobility	hydrogen fuel-cell	e-train	Interesting Engineering	2016	http://interestingengineering.com/worlds-first-zero-emissions-hydrogen-powered-train/
Energy Generation	nuclear fusion	tokamak fusion reactor	Interesting Engineering	2016	http://interestingengineering.com/worlds-largest-fusion-reactor-harness-power-sun/
Energy Generation	microwave energy transmission	interstellar solar-energy harvesting	interesting Engineering	2016	http://interestingengineering.com/using-flying-carpets-to-light-the-world/
Energy Generation	thermo electric materials	solar thermoelectric generator	Interesting Engineering	2016	http://interestingengineering.com/its-solar-power-but-not-as-you-know-it/

Figure 3: Extract of technology catalog[17]

1.5 Structure of the Thesis

Chapter 2 shows the integration of technology assessment (TA) in the technology management (TM) process, which is used in firms. Moreover, this chapter gives a short insight in the different phases within TM and where TA tools can be applied.

Chapter 3 lists gathered TA methods and tools. Also visualization options for decision support of evaluated technologies are introduced. This chapter ends with recommended literature TA approaches, which imply already a number of TA methods, and an analysis of their practical suitability.

Chapter 4 is drawn up by the limitations of the TA approach analysis of Chapter 3 and shows the development of a new assessment approach, which can be used by an investor. Each phase of the developed three step approach for TA is explained in detail.

The thesis ends by giving a conclusion to the developed TA approach and an outlook for the approach as well as for TA in general in chapter 5.

[17] Institute of Innovation and Industrial Management

2 Technology Management

Companies achieve competitive advantage by continuously implementing new technologies to their products to strengthen their core competencies. To ensure that emergent technologies will be detected and applied useful in the end for keeping competitive advantage, this chapter shows a structured technology management (TM) process which serves as guideline for dealing with technologies within firms. In order to show how TA is part in the TM process, this chapter deals also with the appropriate integration in the TM process.

2.1 Technology Management Process

Technologies have fundamentally influence on the competitiveness of firms. However, they are also a threat for firms, which success is based on obsolete technologies. Thus, companies are forced to develop, to apply and to substitute technologies timely. This is the issue where technology management starts.[18]

According to the literature, tasks and focus areas of TM are identified. Drawn up by the previous mentioned problems, a structured TM process including the linked main activities of the literature is developed.[19] The process is divided into following stages:[20]

- Technology early detection
- Technology planning
- Technology development
- Technology application
- Technology protection

With the aid of this process, firms have a tool to keep and strengthen the competitive situation of their company. The following subchapters discuss each step within the TM process.

[18] Cf. Klappert et al. (2011a), p.6
[19] Cf. Schuh et al. (2011b), p.14-15
[20] ibidem

2.1.1 Technology Early Detection

Technology early detection is a part of the strategic early detection within a company (business intelligence). The objective of the early detection is to gather timely relevant information about changes within the companies' environment for recognizing opportunities and risks. The creation of a transparent information base supports strategic decision processes within the enterprise and represents the link between strategy formulation and technology planning. Whereas early detection concentrates on future developments and happenings in the companies' environment, the focus of technology early detection is as part of these activities on the analysis and forecast of technological potentials as well as the determination of technological limits. The aim is to identify developments in relevant technology fields as foundation for technology decisions.[21]

2.1.2 Technology Planning

Planning includes the investigation and systematization of all actions, its process as well as their costs, resources and appointments and represents the anticipation for future acts[22]. In the context of technology planning, this means that decisions for the technological orientation of the company have to be made including a forethought for its implementation[23]. Questions like: which technologies lead to an increase of revenue and market share, how to fulfill better customer needs, how to strengthen the firms' potentials, how to gain competitive advantages or how to deepen strengths and reduce weaknesses have to be answered[24].

The technology plan (mostly illustrated as a technology roadmap, see chapter 3.4.3) is the core result of technology planning and discusses when which technologies and for what purpose have to be applied. Moreover, the plan provides information where to acquire these technologies and which requirements for resource planning apply.[25]

2.1.3 Technology Development

Technology development includes the guarantee of suitable usage of technologies in products and also in the manufacturing process. In a broader sense this contains work

[21] Cf. Wellensiek et al. (2011), p.89
[22] Cf. Strebel (2007), p.227
[23] Cf. Schuh et al. (2011c), p.171
[24] Cf. Pleschak/Ossenkopf (2002), p.337-338
[25] Cf. Schuh et al. (2011c), p.171

within applied research, and advance development and technology development in the narrower sense. The focus of technology development is based on effectiveness, where a systematic process tries to select, to develop, and to validate technologies. Afterwards the objective is to transfer these suitable, applicable and riskless technologies to the departments of product and process development. Therefore, the main topics in technology development are creativity, level of innovation and customer benefit, whereas in product development the aspects of quality, costs and time are important.[26]

2.1.4 Technology Application

The strategic operational framework of technology application is divided in “intern technology application” and in “extern technology application”. The focus of intern technology application is the usage of unique technologies in products of the company. On the one hand the objective for companies is to gain competitive advantage with the usage of innovative technologies, on the other hand another goal is to spread new technologies in a various of products, sales markets and branches. Technological success can also be achieved through extern technology applications. By allowing the usage of technologies to a third party, the profitability for technology investment gets strengthen and in addition a share to an economic benefit is given. As example, this implies organizational cooperation like strategic alliances or joint ventures, licensing and the sale of technologies.[27]

2.1.5 Technology Protection

The aim of technology protection is to use the own innovation power to protect technology developments from the know-how shift to competitors. Hence, shrewd protection mechanisms are developed to protect technologies and products from imitations. This could imply for example the artificial generation of complexity of a product. Barriers can also be created through additional customer specific benefits, Chinese walls within the supply chain or exclusive obligations of suppliers. Targeted and systematic efforts allow to handle threats against undesirable know-how shifts.[28]

[26] Cf. Klappert et al. (2011b), p.223
[27] Cf. Schuh et al. (2011a), p.241
[28] Cf. Neemann/Schuh (2011), p. 283

2.2 Technology Assessment Integration

The introduced technology management process for firms in chapter 2.1 is completed by technology assessment. A high performance within TA is an important requirement for an effective and efficient design of technology management. Figure 4 shows the integration of TA within the TM process. Tools and methods for evaluating technologies are used in each stage of the process. The ability for choosing, applying and controlling of TA tools and methods inside the different stages is of high importance.[29]

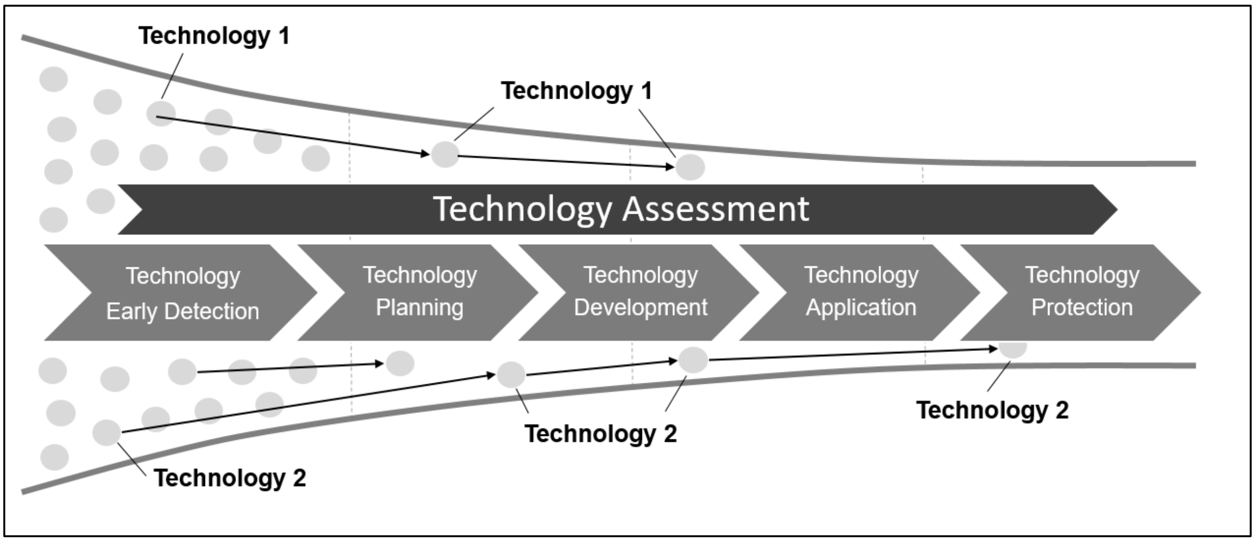


Figure 4: Technology management process[30]

As seen in Figure 4, the stage of technology early detection deals with a high number of different technologies, whereas in the stage of technology development only a few technologies are left. Aim of the TM process and TA is to reduce the number of technologies to these ones, which are applicable to the firms' technology field and have the most potential for being successful in the future. Therefore, in each stage of the TM process appropriate TA methods and tools are necessary to support and make founded decisions.[31]

Since a TM process is indispensable for an enterprise to deal with new technologies from their detection to their protection in a structured way, an investor is mostly interested in the step of technology early detection and in an ongoing potential technology investment. More details to this issue are found in chapter 3.5.3 and in chapter 4.

[29] Cf. Klappert et al. (2011b), p.17
[30] Cf. Schulte-Gehrmann et al. (2011), p.86
[31] Cf. Haag et al. (2011), p.309-311

3 Technology Assessment

Technology assessment (TA) deals with the investigation and evaluation of the degree of fulfillment of defined aims for a technological oriented assessment object. Thus, decisions for development, launching and application of technologies are made. Moreover, the usage of assessment tools allows to increase the quality of decisions and hence the probability of its success.[32]

The subject of TA has been undergoing a huge change over the past decades. Although TA has been developed, there is still a need for methods, tools and approaches, which are more effective and can be applied universally.[33]

As mentioned in the previous chapter, TA is part in each stage of the TM process. The aim of the appropriate tools and methods is to prepare a decision basis on complex information. These tools and methods are structured in qualitative and quantitative methods. Whereas in the beginning of the TM process qualitative methods are dominating, in later steps quantitative methods are preferred. For each decision within the TM process, appropriate methods have to be chosen. It is important for the usage of the different methods to understand, how their assessment logic is working. Only then the assessment result is comprehensible and discussable.[34]

Figure 5 shows the three stages and issues of TA:

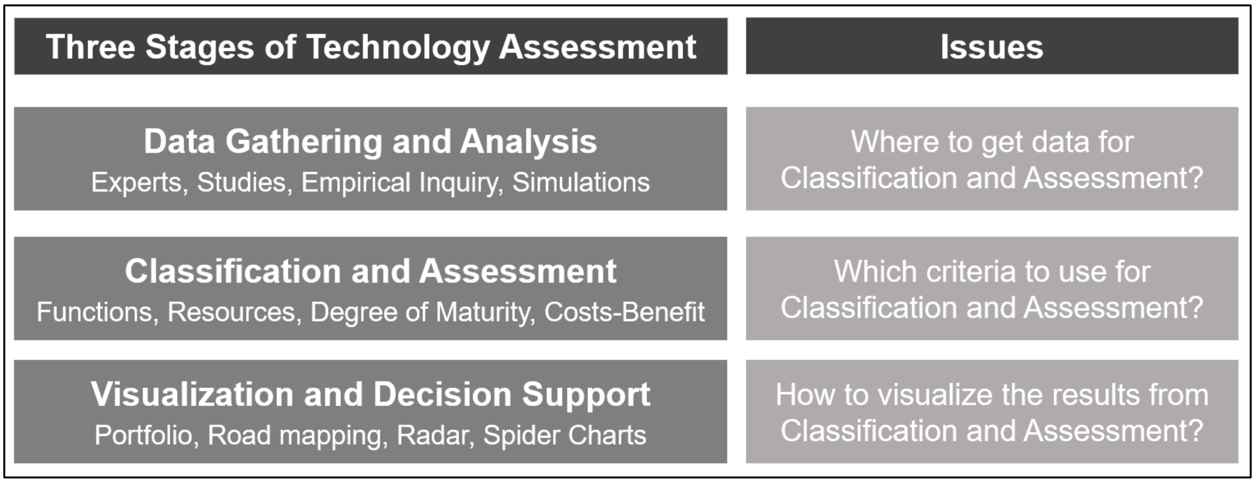


Figure 5: The three stages of technology assessment[35]

[32] Cf. Schuh et al. (2011b), p.17
[33] Cf. Tran (2007), p.1651
[34] Cf. Haag et al. (2011), p.309-311
[35] Cf. Schimpf/Rummel (2015), p.50

The stages of data gathering and classification are at some points conducted simultaneously, since evaluation criteria can only be defined on available data. Based on data gathering, classification and assessment within the first two stages, a visualization of the assessment results supports the technology decision in stage three. Additionally, it allows a comparison of a variety of technologies with a consistent visualization. More information to each stage is given in the chapters 3.1 to 3.4.[36]

The following chapter deals with how to gather assessment data, how to classify and define criteria, which assessment methods and tools exist and are used for what purpose and how to visualize assessment results. The chapter ends with discussing gathered assessment approaches from literature and gives the framework for the developed assessment approach in chapter 4.

3.1 Data Gathering and Analysis

The gathering of data and its analysis is the foundation of TA. With the aid of the collected information, technologies can be evaluated based on defined criteria and the results can be visualized afterwards.[37]

The following subchapter 3.1.1 is dealing with how sources can be categorized, whereas subchapter 3.1.2 offers available methods and tools to get the relevant data the user is expecting. Aim of the overall chapter is to show how to collect relevant data in a structured and systematic way[38].

3.1.1 Source Categorization

To get more aware of where relevant technology data can be found and to use it in a structured way, it is necessary to categorize information sources. This categorization supports afterwards the decision, which methods and tools should be used to get all needed data. Following classification for sources is common:[39]

- **Primary and secondary information sources**
  Primary sources are data, which are collected by own work. This could be a direct analysis of a technology by defined criteria or with the support of experts and customers, who are developing or using the technology. Secondary sources are

[36] Cf. Schimpf/Rummel (2015), p.49-51
[37] Cf. Schimpf/Rummel (2015), p.57
[38] Cf. Schimpf (2010), p.47
[39] Cf. Kotler/Keller (2016), p.63; Cf. Schimpf (2010), p.48-49; Cf. Wellensiek et al. (2011), p.142-150

data, which are already available like reports or books. Depending on which information is required and which resources are available, users choose between primary and secondary information. The big advantages of secondary sources are the less gathering effort since it exists already in a structured form, and the inexpensive availability. Indeed, primary sources have the advantage of collecting only really needed information.

- **Internal and external information sources**
  This kind of sources are structured in three areas: In a) information sources in the organization, in b) information sources outside the organization but inside the industry and in c) information sources outside the industry. The advantage of external information is to get a better overview beyond its own organization.

- **Formal and informal information sources**
  Formal information sources are always structured and reliable information, whereas informal information have no structure and are mostly based on personal communication.

3.1.2 Information Monitoring

One of the most important steps within information monitoring before starting with the actual search process is the identification and specification of search fields. The objective of these fields is the determination of needed information and furthermore they are indispensable to avoid redundancies and an overload of information through the monitoring process[40].

Figure 6 shows a list of structured main sources for the collection of required information. Depending on which information is needed, different sources are chosen for a search portfolio and applied afterwards. Each categorization of the list offers also examples for how and where to gather the right data. Additionally, a source categorization analysis according to chapter 3.1.1 is given.[41]

To get a high quality of collected information, qualified people (e.g. internal experts) are one of the most important sources. Therefore, responsibilities and tasks should be distributed carefully.[42]

[40] Cf. Wellensiek et al. (2011), p.142-150; Cf. Schimpf (2010), p.42; Cf. Lichtenthaler (2003), p.112
[41] Cf. Kotler/Keller (2016), p.63-64; Cf. Wellensiek et al. (2011), p.147-148; Cf. Schimpf (2010), p.50
[42] Cf. Schimpf (2010), p.50

Information Source	Internal	External	Primary	Secondary	Informal	Formal
Committees and associations (norming committees, professional associations, etc.).	●	●	●		●	
Corporations with companies (through joint ventures, alliances, cross-sectoral cooperation, etc.).		●	●	●	●	●
Databases (patents, statistics, etc.).	●	●		●		●
Events (conferences, fairs, seminars, etc.).		●	●	●	●	●
Experts (researchers, engineers, specialists, etc.).	●	●	●		●	
Governmental and public institutions (ministries, regulatory bodies, etc.).		●	●	●	●	●
Information broker (external specialists, consultants, etc.).		●	●		●	●
Internet (company websites, forums, specialised platforms, etc.).		●		●		●
Research institutes or universities (through research projects, PhD students, etc.).		●	●		●	
Publications (journals, books, press, etc.).	●	●		●		●
Stakeholder (users, clients, suppliers, etc.).		●	●		●	●
Technology studies (Delphi studies, competitive analyses, technology analysis etc.).	●	●		●		●

Figure 6: Sources of information monitoring[43]

3.2 Criteria for Classification and Evaluation of Technologies

It is necessary to classify technologies in different types, as it makes a difference for TA for choosing the appropriate assessment methods as they vary depending on technology fields, technology types and application areas. This assignment of technologies to distinct technology categories implies a further benefit by delivering the option of comparison for evaluated technologies. Moreover, it allows based on the technology comparison to prioritize technologies for its development or usage within a firm.[44]

Table 1 shows a selection for the type of classification technologies can be structured in. The column "technology categories" provides varieties and examples to each type.

[43] Schimpf (2010), p.50
[44] Cf. Schimpf/Rummel (2015), p.54

Table 1: Selection of classification types for technologies[45]

CLASSIFICATION TYPE	TECHNOLOGY CATEGORIES
Branch reference	Horizontal technologies, specific technologies
Type of usage	Product, application, service, production technologies
R&D intensity	Low, medium and high-class technologies
Function	Examples: linkage, separating, motion or measure technologies
Interdependencies	System, single, complementary, competitiveness and substitutions technologies
Long-term impact	Sustainability, energy saving and lightweight technologies
Life cycle stages	Pacesetter, key, base and replaced technologies
Visibility	Technologies which are visible or invisible for the customer
Strategic relevance within system	Core technologies; peripheral, supporting and enabling technologies
Strategic relevance within firm	Core competence and boundary competence technologies
Systemic impact	Maintaining, supplementary and destructive technologies
Technological characteristics	Examples: nano, surface, information or organic technologies
Science independence	None, below average, above average, intense
Customer anticipation	Basis, performance and excitement technologies
Field	Example: based on international patent classifications
Performance oriented or firm specific	Corresponding to products, processes, services or to components in firms

The listed classification types in Table 1 deliver different TA scenarios. For conducting a detailed TA, the technological characteristics and its discipline are influential to choose competent methods. Before actions for TA are set, the strategic relevance for an enterprise has to be analyzed. The overall objective of classifying technologies lies in the support for storing, filtering, searching and allocating technologies and its information. Depending on the companies' level, technology relevant decisions can deal with strategic as well as operational issues. Therefore, appropriate assessment criteria and their

[45] Cf. Schimpf/Rummel (2015), p.54-55

following usage for technology evaluation allow to compare technologies and technology fields. As a result, transparency to technological decisions is achieved.[46]

A common categorization of TA criteria is the differentiation in:[47]

- **Market related criteria**
  These criteria are aiming to the acceptance and success of a technology on the market. Criteria such as market volume, profitability, market volume, the level of competitiveness, the level of replaceability, the economic situation and environmental issues are possible options[48].

- **Technology related criteria**
  These criteria assess the technological feasibility, available and required competences and resources as well as the integration in present or new technological systems. Criteria such as the maturity of the technology, the potential of development, technological alternatives or dynamic trends are possible options[49].

Table 2 illustrates a consolidated list of assessment criteria. These criteria are based on the collection of Schimpf and descend from a various of TA methods and tools[50]. The consolidated list provides a definition to each criterion and for what purpose it is used. The capital letter “M” in the last column describes a market criterion, while the capital letter “T” stands for a technology criterion. For a more detail listing to all potential applicable criteria see Appendix B.

Despite of getting through these criteria a result for technology prioritization and technological decisions should never be made only based on these evaluation criteria. It always has to be scrutinized who conducted the assessment, which assumptions are made for the evaluation and from where the data is collected. Additionally, there is a tendency to prefer these options, where a sufficient and founded information source exists and the uncertainty is hence less[51]. Also, enterprises filter sometimes technologies which are new to them and which and can lead to missed chances and higher risks.[52]

[46] Cf. Schimpf/Rummel (2015), p.55
[47] Cf. Schimpf/Rummel (2015), p.56
[48] Cf. Pleschak et al. (1994), p.132
[49] Cf. Metze (2008), p.337-341
[50] Cf. Schimpf (2010), p.224-228
[51] Cf. Pillkahn (2013), p.129-130
[52] Cf. Schimpf/Rummel (2015), p.57

Table 2: Consolidate list of assessment criteria[53]

ASSESSMENT CRITERIA	DEFINITION	M/T[54]
Dependencies	Dependencies between technologies within a system	T
Acceptance	Level of acceptance of a technology on the market	M
Applicability	Level of applicability of a technology in products, processes, components and services	T
Wide of usage	Spread of technology usage beyond products, processes, components and services	M
Dominance	Level of dominance of a technology within a market	M
Development potential	Potential of development of a technology	T
R&D resources	R&D resources, which are available for technology development	T
Investment until market launch	Raising investment until technology is usable for the market	T
Compatibility	Level of compatibility with regulations and experiences of present solutions	T
Competences	Existing technology competencies	T
Cost-benefit customer	Cost-benefit asset for customers through technology usage	M
Cost-benefit firm	Cost benefit asset for firm through technology usage	T
Performance edge	Performance edge compared to reference technologies	T
Market volume	Size of market through technology usage	M
Public claims	Public claims through public institutions	T
Patents	Number of patents, which are existing within and outside of the firm	T
Level of maturity	Stage of technology within technology life cycle	T
Risk	Occurring risk through technology usage	T
Strategic relevance	Relevance of technology for the strategic orientation of the firm	M
Strategic consistence	Consistence of technology with strategic orientation	T
Synergies	Synergies, which can emerge through usage and development of a technology	T
Value added contribution	Contribution of technology for value adding to the customer	M

[53] Cf. Schimpf/Rummel (2015), p.56-57
[54] Legend: (M) Market, (T) Technology

3.3 Evaluation Methods and Tools

This chapter deals with TA methods and tools, which are used differently by institutions to evaluate technologies. TA covers a wide range of methods as the traditional analytic methods like financial evaluation over to more radical methods. Since of the introducing of TA in the 1970's, a shift from analytical methods to approaches with a broader scope has been noticed as of new perspectives for TA in the contemporary world.[55]

For technology managers it is important to have a range of TA options, since different technologies needs different methods to get a reliable TA result[56]. On the one hand, TA methods are classified according to Haag to the stages of the technology management process of firms introduced in chapter 2.[57] On the other hand, according to Henriksen, TA methods are categorized based on their intended purpose in:[58]

- Technical performance assessment
- Risk assessment
- Market analysis
- Economic analysis
- Technological forecasting
- System engineering and system analysis
- Externalities and impact analysis
- Further useful methods for TA

These categorization of methods is used in the ongoing thesis as an investor can choose methods for a certain evaluation purpose. All gathered methods and tools are based on TA studies, where they are already applied. Some methods can also be applied in different categories. It is possible to apply only one method to support a decision, but many researchers use this toolkit of methods to combine different ones to get a more informed and broader evaluation result.[59]

The objective of TA methods for each firm is to assess the competitive position of its product, process or supporting technologies within their life cycle, whereas the overall aim of TA methods is to support enterprises with the relevant evaluation results to make the right decisions for their strategic technology planning. Thus, the risk for focusing or investing in not future oriented technologies can be reduced.[60]

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[55] Cf. Tran (2007), p.1654
[56] Cf. Henriksen (1997), p.615
[57] Cf. Haag et al. (2011), p.311-313
[58] Cf. Henriksen (1997), p.617
[59] Cf. Tran (2007), p.1652
[60] Cf. Henriksen (1997), p.616

3.3.1 Technical Performance Assessment

Table 3 contains potential methods to evaluate the technical performance of technologies. The objectives of these methods is the determination of:[61]

- How well performs a technology as expected?
- Evaluation of characteristics of a technology

Possible examples for the evaluation of its characteristics implies values like performance limits, operating costs, ergonomic considerations, breakdown rates, efficacy and effectiveness. In addition, all technologies which are computer based are evaluated by their productivity impact to the enterprise. The technical performance assessment has different objectives depending on if product technologies, process technologies or supporting technologies have to be evaluated. A product technology assessment helps to keep the market position, whereas an assessment of process technologies and supporting technologies aim for a high reliability in the manufacturing process. Through technical performance assessment, information if a new process is more cost-effective or if an emerging product implies any risks are collected. Therefore, the quality control of enterprises has to set standards for the performance assessment of its products.[62]

Table 3: Methods and tools for technical performance assessment[63]

TECHNICAL PERFORMANCE ASSESSMENT
Statistical Analysis
Bayesian Confidence Profile Analysis
Surveys, Questionnaires
Trial Use Periods
Beta Testing
Technology Decomposition Theory
S-Curve Analysis
Human Factors Analysis (Ergonomics studies, Ease-of-Use studies)
Outcomes Research
Technometrics
Technology Attribute Matrix

[61] Cf. Henriksen (1997), p.626
[62] ibidem
[63] Cf. Henriksen (1997), p.618; Cf. Tran (2009), p.1654; Cf. Decker/Ladikas (2004), p.29-32; Cf. Ardilio (2012a), p.67-69; Cf. Wellensiek et al. (2011), p.150-151

3.3.2 Risk Analysis

The aim of doing a risk analysis is to avoid troubles for the firms' business. Although up-costs are implied for an analysis, the money is well spent since only one not conceived technology is possible to ruin the whole business of the firm.[64]

Table 4 illustrates a list of applied risk assessment methods. The purpose of these methods lies in the analysis of technologies to determine:[65]

- If a technology incurs risks to the company?
- If risks are detected, what are they?
- What is the respective character of these risks?
- How can these risks be handled?

Although all risks are derived from uncertainty, risks and uncertainties are different and hence not the same. A quantitative risk definition is found by multiplying the probability that an event may occur with the amount of loss that would result if it really arises.[66]

Risks can occur through many different circumstances. Examples of arising risks can be through:[67]

- Product defects
- Unforeseen side effects of the product
- Responding to the market too slowly
- A too fast movement of the product to the market
- Ignoring technical data issues such as environment, safety or health

Table 4: Methods and tools for risk assessment[68]

RISK ASSESSMENT
Simulation Modeling and Analysis
Probabilistic Risk Assessment
Environment, Health and Safety Studies
Risk-based Decision Trees
Litigation Risk Assessment

[64] Cf. Henriksen (1997), p.628
[65] ibidem
[66] ibidem
[67] ibidem
[68] Cf. Henriksen (1997), p.618; Cf. Decker/Ladikas (2004), p.29-32

3.3.3 Market Analysis

The objective of market analysis is to identify:[69]

- Desired customer features and characteristics of a technology
- The price customers are willing to pay for their benefit

In addition, a market analysis provides information to forecast:[70]

- Revenue/profit
- Demand data for production planning

Therefore, Table 5 shows market analysis methods to achieve these goals. Through the founded analysis, market signals are detected and differentiated in market-pull and market-push strategies. Moreover, feedback to existing products is collected and hence improvements to the firms' products be made. Also, long-term ideas for R&D orientation can be derived.[71]

A market analysis should always be conducted before developing a new technology, but it can as well go together with the development. It is also important to do a market analysis after a product has failed. This provides valuable information why a product could not penetrate the market and let the firm derive actions for the future for not making the same mistakes again.[72]

Table 5: Methods and tools for market analysis[73]

MARKET ANALYSIS
Fusion Method
Market Push/Pull Analysis
Surveys/Questionnaires
S-Curve Analysis
Scenario Analysis
Multigeneration Technology Diffusion
Portfolio Analysis

[69] Cf. Henriksen (1997), p.628-629
[70] ibidem
[71] ibidem
[72] ibidem
[73] Cf. Henriksen (1997), p.618; Cf. Tran (2007), p.1654; Cf. Decker/Ladikas (2004), p.29-32; Cf. Wellensiek et al. (2011), p.150-151; Cf. Bruhn (2001), p.70-74

3.3.4 Economic Analysis

Table 6 lists potential methods for doing an economic analysis. The aim is to investigate and quantify financial costs, benefits and ramifications of a technology. Part of an economic analysis can be only quantifiable costs like operating costs and acquisitions (e.g. return on investment), or also non quantifiable costs like social costs (e.g. cost-benefit analysis).[74]

For a comprehensive TA, the economic analysis is an important component since it supports decision makers and has hence a high impact to the firms' balance sheet and profit. Attention should also be given to the understandings of assumptions which are made for conducting the analysis. Therefore, all assumptions should be stated before starting the assessment to ensure result transparency.[75]

Table 6: Methods and tools for economic analysis[76]

ECONOMIC ANALYSIS
Cost/Benefit Analysis
Cost/Effective Analysis
Life-Cycle Cost Assessment
Return on Investment (ROI)
Net Present Value (NPV)
Internal Rate of Return
Break Even Point Analysis
Payback Period Analysis
Residual Income
Total Saving
Increasing Returns Analysis
Technology Value Pyramid
Real Options
Technology Balance Sheet
Total Cost of Ownership

[74] Cf. Henriksen (1997), p.617
[75] Cf. Henriksen (1997), p.620
[76] Cf. Henriksen (1997), p.618, Cf. Tran (2007), p.1654; Cf. Haag et al. (2011), p.312; Cf. Wellensiek et al. (2011), p.150-151

3.3.5 Technological Forecasting

With the aid of technological forecasting, a prediction to future technological directions based on detected dynamic changes should be achieved. This forecast does not guarantee what will happen, but only tries to understand what could happen in the future. Thus, a technological forecast is only as good as the used information and the respective person who conducts it.[77]

Table 7 contains a list of common technological forecast methods which determine:[78]

- Dynamic changes through collecting information to a technology performance
- Substitution rates of new products
- Technological trends for strategic technology planning
- Goals for R&D efforts
- Specific incremental improvements to existing technologies

Overall, technological forecast methods should always be applied when necessary to understand the technology's past, present and future. Thereby, the firm get at least some control over its future. To get a credible technological forecast, it is important to understand and to state all assumptions which are made for the forecast. But as important as conducting a trustworthy forecast is the ability to recognize a credible technological forecast.[79]

Table 7: Methods and tools for technological forecasting[80]

TECHNOLOGICAL FORECASTING
S-Curve Analysis
Delphi, Analytical Hierarchy Process, Q-Sort
R&D Researcher Hazard Rate Analysis
Trend Exploration
Correlation and Causal Methods
Probabilistic Methods
Monte Carlo Simulation
Roadmapping

[77] Cf. Henriksen (1997), p.623-625
[78] ibidem
[79] ibidem
[80] Cf. Henriksen (1997), p.618; Cf. Tran (2007), p.1654; Cf. Decker/Ladikas (2004), p.29-32; Cf. Schuh et al. (2011c), p.207-2011; Cf. Wellensiek et al. (2011), p.150-151

3.3.6 System Engineering and System Analysis

System engineering and system analysis deals with the relationship of the firms' profitability to a technology (product, process or supporting technologies) as a system and implies all factors that influence the system performance and outcome. Thus, part of the assessments are physical and functional parts of the system as well as the operational environment and human factors. The aim is to identify parameters of the technology system to optimize the performance of a company.[81]

Possible tasks of system engineering are to determine:[82]

- Which technological innovations or acquisitions provide the highest return on investment (ROI)?
- Which technology competences outside the firm can be detected and implemented?

Table 8 lists different methods to conduct a system analysis. Compared to other TA analyses, TA is not done by delivering a technology or when the decision is made. An on-going analysis regarding lessons learned and potential improvements helps to continue optimizing the technology system.[83]

Table 8: Methods and tools for system engineering and system analysis[84]

SYSTEM ENGINEERING AND SYSTEM ANALYSIS
Technology System Studies
System Dynamics
Simulation Modeling and Analysis
Interpretive Structural Model
Bimodal System Dynamic Approach
Project Management Techniques
System Optimization Techniques (Linear, Integer and Non-linear programming)
Linear Programming
Technology Portfolio Analysis

[81] Cf. Crepea (1995), p.297; Cf. Henriksen (1997), p.622
[82] Cf. Henriksen (1997), p.622
[83] ibidem
[84] Cf. Henriksen (1997), p.618; Cf. Tran (2007), p.1654; Cf. Haag et al. (2001), p.331; Cf. Decker/Ladikas (2004), p.29-32; Cf. Wellensiek et al. (2011), p.150-151

3.3.7 Externalities and Impact Analysis

Incidents caused by a technology that impacts members of the society or the ecosystem are called externalities. Although they have no direct cost influence to a firm, they indirectly impact their business by reducing the firms' market share and revenue. Therefore, technology managers have to be aware that negative externalities can affect the firms' success.[85]

Whereas externalities like environment pollution are perceptible immediately, their impact may last for many years. In some cases, it may also take many years until the impact of externalities is noticeable for the society.[86]

Externalities can also be a cost driver for enterprises. Through establishing new laws or regulations in the firms' technology field, firms are forced to comply to keep their business alive and have to adopt their respective technology.[87]

Table 9 contain the common methods to analyze externalities and their impact like social, political, environmental or cultural issues.

Table 9: Methods and tools for externalities and impact analysis[88]

EXTERNALITIES AND IMPACT ANALYSIS
Externalities Analysis
Social Impact Analysis
Political Impact Analysis
Environmental Impact Analysis
Ethical Issues Analysis
Cultural Impact Analysis
Integrated Impact Analysis
Life Cycle Analysis

[85] Cf. Henriksen (1997), p.630-631
[86] ibidem
[87] ibidem
[88] Cf. Henriksen (1997), p.618; Cf. Tran (2007), p.1654; Cf. Decker/Ladikas (2004), p.22-25; Cf. Paxmann/Fuchs (2005), p.82-83

3.3.8 Further Useful Methods

The methods and tools introduced in the subchapters 3.3.1 to 3.3.7 are categorized based on their intended purpose. However, not for all gathered methods a respective categorization has been found.

Table 10 shows TA methods, which could not be integrated in the mentioned structure, but which can be useful for TA though.

Table 10: Further methods and tools useful for technology assessment[89]

FURTHER METHODS AND TOOLS USEFUL FOR TECHNOLOGY ASSESSMENT
Technique for Order Preference by Similarity to Ideal Solution
Strategic Technology Assessment Review
System Wide Benefits Value Analysis
Scenario-Based Assessment Model
Internet-Accessible Technology Risk Assessment Computer System
Mathematical Technology Assessment Model
Multiregional Approach for Resource and Industry Allocation
Argument Balance Sheets
Check Lists
ABC Analysis
Strengths Weaknesses Opportunities and Threats (SWOT) Analysis
Porter's Five Forces

[89] Cf. Tran (2007), p.1654; Cf. Haag et al. (2011), p.312; Cf. Disselkamp (2012), p.141-142; Cf. Porter (2008), p.78-93; Cf. Decker/Ladikas (2004), p.29-32

3.4 Visualization and Decision Support

The visualization of the different technology classifications and assessment criteria of chapter 3.2 with their respective evaluation result is important as communication tool for the support of decision makers. Additionally, the generated visualization serves as external communication to suppliers or customers.[90]

Based on the assessment purpose, following structure is used for possible visualization options of technology evaluation results:[91]

- **Visualization of single assessment of technologies**
  These visualization methods serve to identify the potential or maturity level of a single technology. Examples of such methods are the technology readiness level (see chapter 3.5.2) to determine the technology's maturity, and technology curves (see chapter 3.4.2).

- **Visualization of assessment of different technologies**
  Through the usage of these methods, different technologies of a single technology field or classification type can be compared and supports the selection process for technology adoption. A common method is a portfolio analysis (see chapter 3.4.4).

- **Overall visualization of classification and assessment criteria**
  The visualization of all relevant technologies serves as steering tool within technology fields and as strategic planning tool for firms. Typical methods are the technology roadmap (see chapter 3.4.3) and the technology radar, which is discussed in chapter 3.4.1.

Next subchapters discuss the common visualization methods and their application more in detail. In addition, the subchapter 3.4.5 deals with methods how to support decision makers and therefore contains a list of potential decision analysis methods.

[90] Cf. Haag et al. (2001), p.337; Cf. Schimpf/Rummel (2015), p.51
[91] Cf. Schimpf/Rummel (2015), p.51-53

3.4.1 Technology Radar

The technology radar visualizes a high number of technologies structured in different technology fields. Figure 7 shows a technology radar, which is derived from a typical radar system and allows one to place technology developments based on its relevance to the firm.[92]

Research institutions and enterprises apply this tool as support for the early detection of new technologies and its assessment on specific requirements[93]. Furthermore, the radar provides information in which year an application of a new technology can be expected (see Figure 7). In addition, the technology radar is used as:[94]

- An early warning system to detect potential threats of different technologies
- A strategic planning tool for the firm
- A tool to identify new competitors with an advanced technology
- A tool to identify substitutions technologies

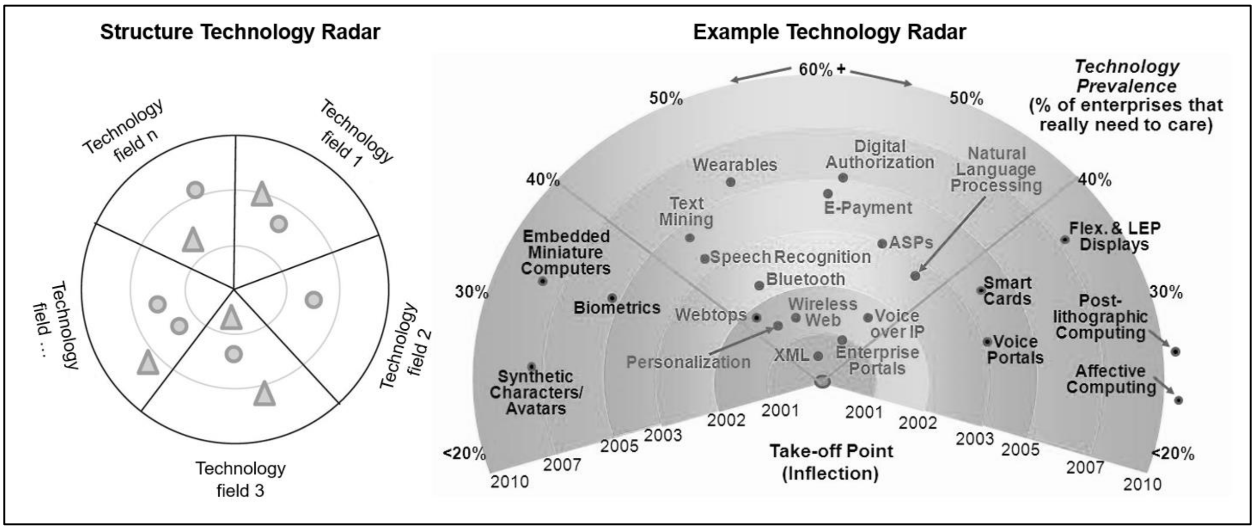

Figure 7: Technology radar[95]

The application of a technology radar is also well suited to follow technologies and its development over a time. Thus, technology trends can be better estimated.[96]

Further details to the technology radar usage and its stages are given in chapter 3.5.1, as it is part of the Fraunhofer Project TA approach, which is discussed in this chapter.

[92] Cf. Wellensiek et al. (2011), p.118-120
[93] Cf. Ardilio (2012a), p.61-62
[94] ibidem
[95] Cf. Schimpf/Rummel (2015), p.53; Gartner conference presentation: www.slideplayer.com (18.01.2017)
[96] Cf. Wellensiek et al. (2011), p.118-120

3.4.2 Technology Curves

Within technology curves, a standard technology development process exists structured in different stages such as in relation to the development of technological competitiveness, the performance or the public attention[97]. Except for the s-curve concept of McKinsey, where the abscissa shows the cumulative R&D effort, the abscissa of technology curves typical uses the time as parameter. Further common technology curves are technology life cycle models by Ansoff or Arthur D. Little.[98]

As shown in Figure 8 as a simple example, technology curves are often used to visualize only a single technology over time for a certain criterion. However, it is also used to visualize several technologies to compare them and to derive strategic actions afterwards. The Hype-Cycle of the consulting and research firm Gartner in Figure 8 illustrates such example for several technologies with an overall ordinate criterion which includes public attention, expectations and trends of future technologies.[99]

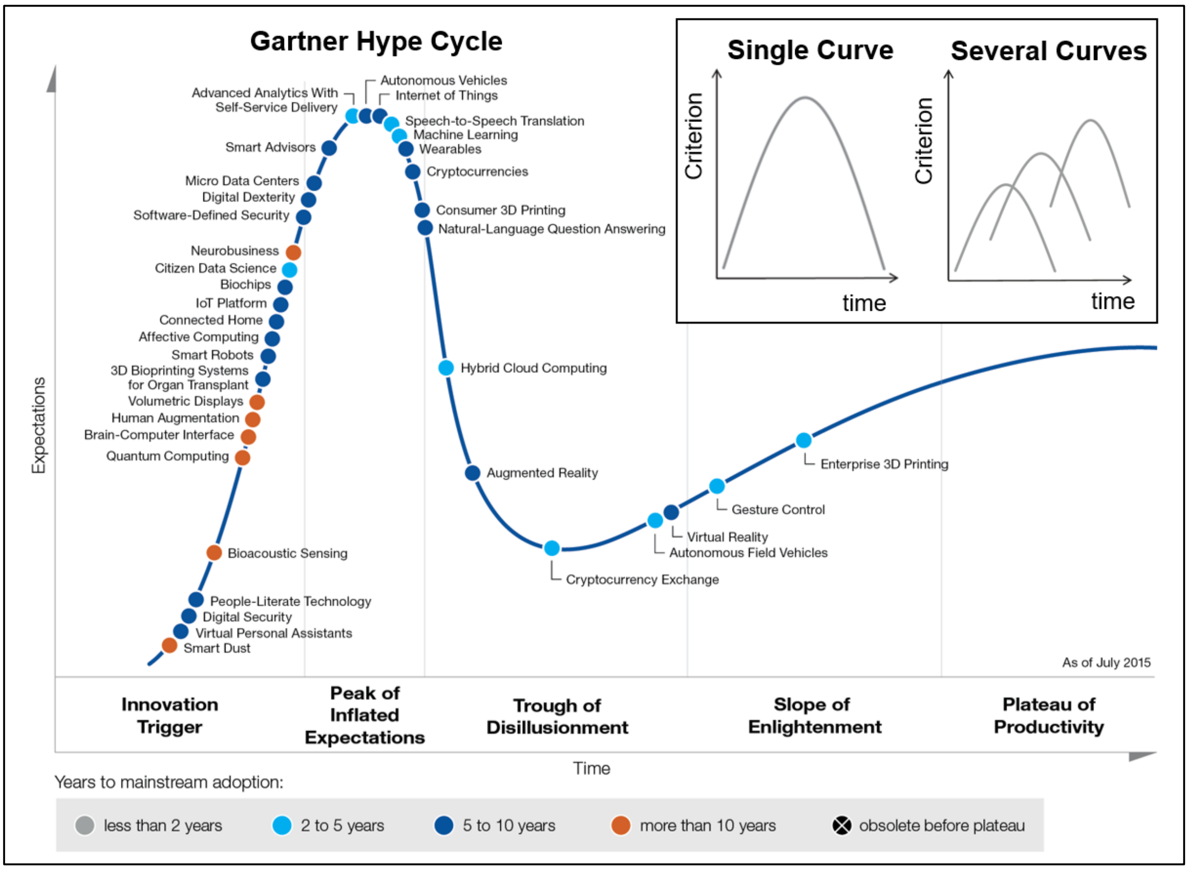

Figure 8: Technology curves[100]

[97] Cf. Michel (1990), p.67
[98] Cf. Schuh et al. (2011d), p.37-47; Cf. Schimpf/Rummel (2015), p.51-52
[99] Cf. Schimpf/Rummel (2015), p.52; Cf. Schuh et al. (2011d), p.37-47
[100] www.gartner.com (19.01.2017); Cf. Schimpf/Rummel (2015), p.52-53

3.4.3 Technology Roadmap

For conducting technology planning, the technology roadmap is an established tool within firms in the industry. Roadmaps provide information about planned actions in the future, about previous decisions as well as dependencies and causalities. In the industry, a various of visualization forms of roadmaps exists based on the specific requirements of the enterprise.[101]

Figure 9 represents a generic form of a roadmap recommended from the European Industrial Research Management Association (EIRMA). The roadmap is structured in the three levels of market, product and technology and shows coherences between planning objects.[102]

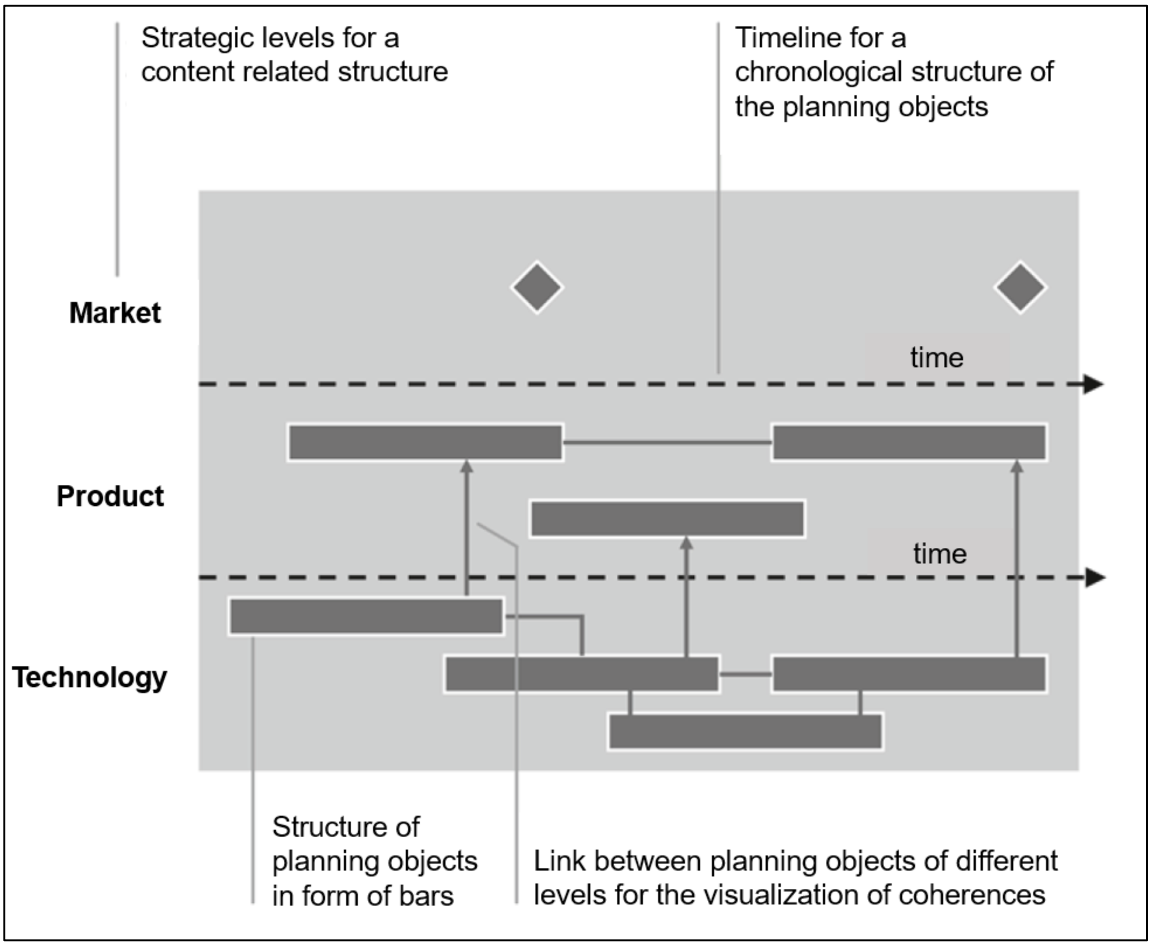

Figure 9: Technology roadmap[103]

[101] Cf. Schuh et al. (2011c), p.207
[102] ibidem
[103] Cf. Schuh et al. (2011c), p.208

3.4.4 Portfolio Analysis

The portfolio analysis belongs to the most frequent tools used in marketing issues. Its origin is the finance investment field, where the objective is to combine assets of commercial papers so that the overall risk and return on investment issues are in an optimal balance.[104]

Portfolio analyses show in a two dimensional display an overview about the market situation of strategic business units, products, customers, competitors or other analysis objects. The aim is to come to a conclusion for a strategic orientation of these objects.[105]

Generally, portfolio analyses are based on three criteria:[106]

- A criterion which is directly influenced by the firm for the abscissa
- A criterion which is not directly influenced by the firm for the ordinate
- A free chosen criterion which determine the diameter of the bubble

To draw up a portfolio analysis, following steps have to be followed:[107]

1. Define analysis object (e.g. business units, products or technology) and define portfolio method (e.g. market portfolio or technology portfolio)
2. Define criteria for the respective axes and choose appropriate assessment criteria
3. Collect relevant information to the objects and conduct evaluation
4. Visualize objects in portfolio and derive strategic actions

One of the most popular portfolios is the market share and market growth portfolio developed by the Boston Consulting Group (BCG)[108]. For analyzing technologies, there exists a number of technology portfolios. The best-known are:[109]

- Technology portfolio by McKinsey
- Technology portfolio by Pfeiffer
- Technology portfolio by Arthur D. Little
- Technology portfolio by Booz, Allen and Hamilton

In the following, the BCG portfolio, the McKinsey portfolio, the Pfeiffer portfolio, the Arthur D. Little portfolio and the portfolio by Booz, Allen and Hamilton are discussed as of their importance more in detail.

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[104] Cf. Bruhn (2001), p.69
[105] Cf. Bruhn (2001), p.69; Cf. Haag et al. (2001), p.319
[106] Cf. Bullinger (1994), p.144
[107] Cf. Haag et al. (2001), p.337; Cf. Bruhn (2001), p.69-70
[108] Cf. Bruhn (2001), p.70
[109] Cf. Haag et al. (2001), p.331

Boston Consulting Group (BCG) Portfolio

The BCG portfolio is defined by the criteria relative market share at the abscissa, and by the market growth rate at the ordinate. Whereas the relative market share describes the ratio of the revenue or shares to the revenue or shares of the biggest competitor on the market, the market growth rate provides information to the overall market growth rate or only of a market segment.[110]

Depending on the evaluation result, the analysis object can be classified in one of the four strategic options (see Figure 10):[111]

- **Stars** have a high market growth rate as well as a high relative market share. Through volume effects in production, effects of cost reduction are achieved. A recommended strategy is to invest in this object.
- **Question marks** have a high market growth rate, but a low relative market share and hence lead to a low cash-flow. After analyzing the chances of market success, a decision regarding market development or its exit has to be made.
- **Cash cows** have a low market growth rate, however, through the high relative market share, a skimming strategy is recommended. Cost reduction potentials should be used and only investments for keeping the market position be done.
- **Poor dogs** have a low market growth rate as well as a low relative market share. These objects are not profitable anymore and a disinvestment strategy by trying to sell this objects or to leave the market is recommended.

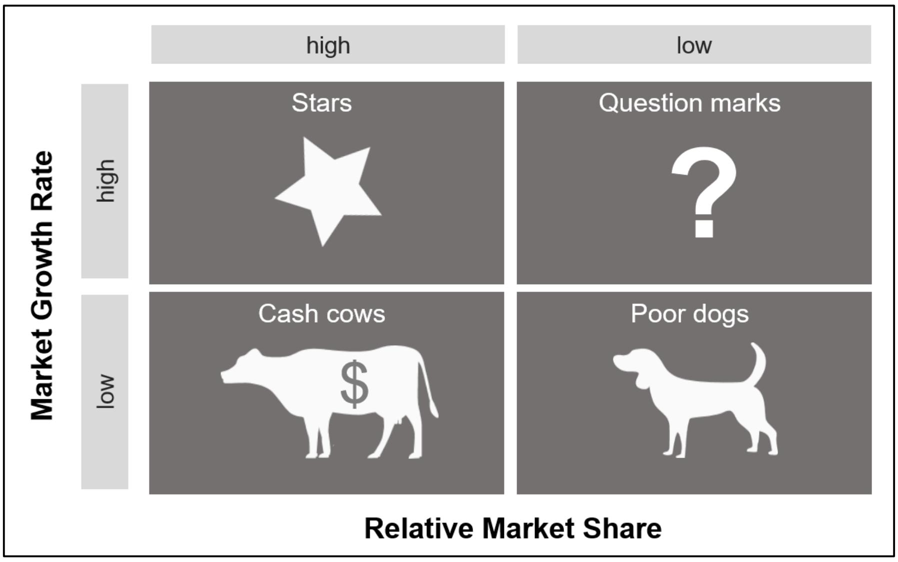

Figure 10 BCG portfolio[112]

[110] Cf. Meyer/Davidson (2001), p.315; Cf. Bruhn (2001), p.70
[111] Cf. Bruhn (2001), p.71-72
[112] Cf. www.slidehunter.com (05.01.2017)

McKinsey Portfolio

The technology portfolio by McKinsey is based on two portfolios (see Figure 11). It combines one portfolio with the dimensions of market attractiveness and relative market position, and another portfolio with the dimensions of technology attractiveness and relative technology position, to one overall technology portfolio with the dimensions of market priority and technology priority.

Indicators for the market attractiveness are:[113]

- Market growth rate and market volume
- Market quality (e.g. competitor intensity or profitability of industry)
- Energy and resources supplies (e.g. existence of alternative suppliers)
- Environmental situation (e.g. legislation or public pressure)

Indicators for the relative market position are:[114]

- Market share
- Revenue
- Relative R&D potential
- Relative production potential
- Size of enterprise
- Growth rate

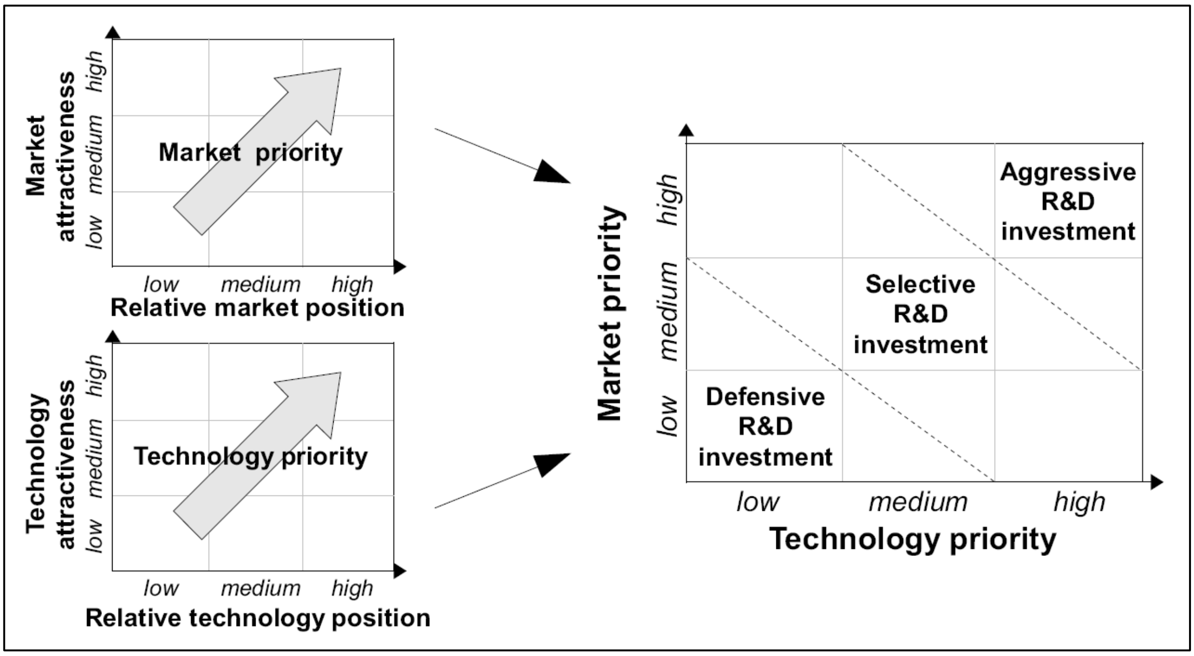

Figure 11: McKinsey technology portfolio[115]

[113] Cf. Bruhn (2001), p.73
[114] Cf. Bruhn (2001), p.72-73
[115] Schimpf (2010), p.216

Indicators for the technology attractiveness are:[116]

- Development potential of a technology
- Revenue and/or cost effect of a technology (e.g. available potential of usage)
- Opportunities and risks (e.g. patent situation, dynamic technical trends or technological alternatives)

The relative technology position is determined through the ratio of how long does it take to develop an innovation within the firm compared to competitors. Since the life-cycle of different technologies various a lot, it is recommended to use absolute time values to determine edges or deficits.[117]

After the evaluation of these two portfolios, the market priority and the technology priority result are combined to a market technology portfolio to derive the respective recommended strategic actions (see Figure 11)[118]. More assessment criteria for the market and technology can be found in Appendix B.

Pfeiffer Technology Portfolio

The technology portfolio by Pfeiffer is based on the two dimensions of technology attractiveness and resource strength (see Figure 12). Whereas the technology attractiveness is dealing with the potential of development, time effort and possible applications, the resource strength contains finance power and know-how strength.

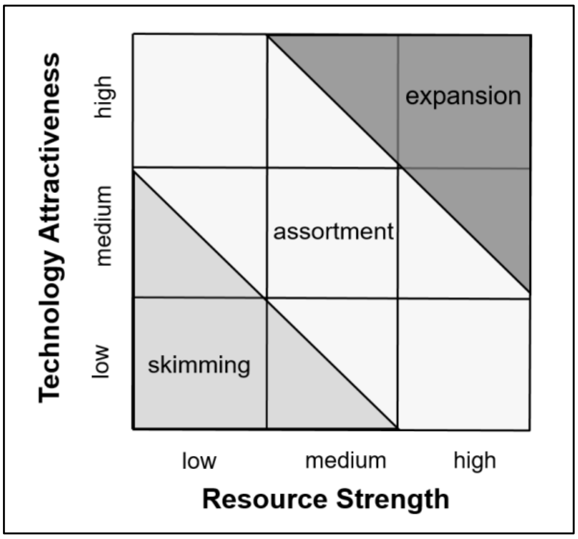

Figure 12: Pfeiffer technology portfolio[119]

[116] Cf. Metze (2008), p.337-341
[117] Cf. Metze (2008), p.341
[118] Cf. Haag et al. (2011), p.336
[119] Cf. Haag et al. (2011), p.334

Technology portfolio by Arthur D. Little

The portfolio by Arthur D. Little in is defined by the dimensions of competitive position (weak, tenable, favourable, strong or dominant) at the ordinate, and by the industry life-cycle (embryonic, growth, mature or growth) at the abscissa (see Figure 13). However, an estimation of the life-cycle stage is difficult, since a technology varies in industries and in its application.[120]

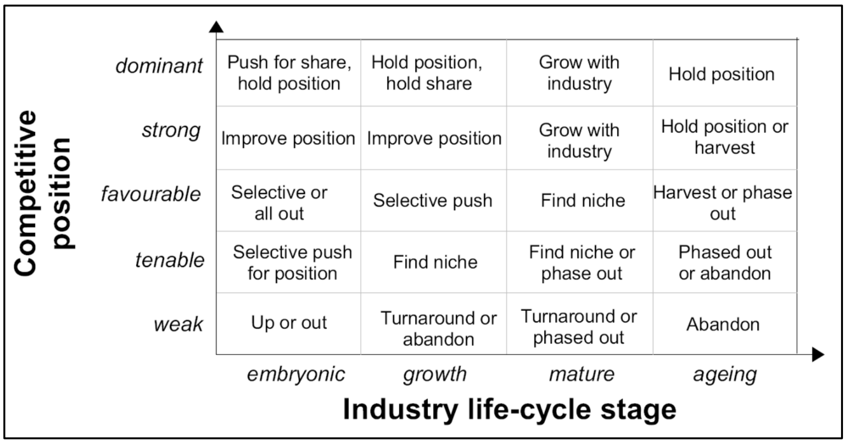

Figure 13: Technology portfolio by Arthur D. Little[121]

Technology portfolio by Booz, Allen and Hamilton

One dimension of this portfolio is the significance of the technology, which implies criteria for market attractiveness, change rate and value creation. The second dimension is the relative technology position (see McKinsey portfolio for sub criteria). After the evaluation, the technology can be classified in one of the four strategy options of draw, bet, fold and cash in, which came from the card game poker (see Figure 14).[122]

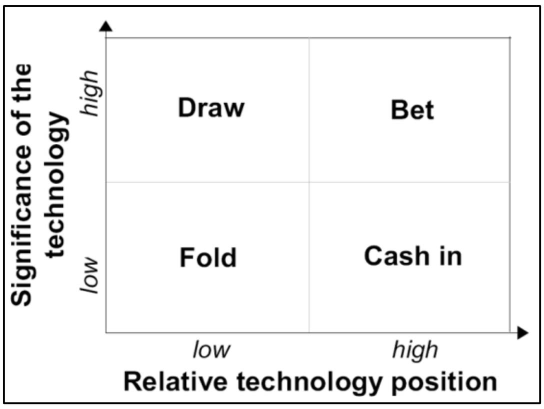

Figure 14: Technology portfolio by Booz, Allen and Hamilton[123]

[120] Cf. Haag et al. (2011), p.331-333; Cf. Schimpf (2010), p.214
[121] Schimpf (2010), p.214
[122] Cf. Haag et al. (2011), p.334-335; Cf. Schimpf (2010), p.213-214
[123] Schimpf (2010), p.214

3.4.5 Decision Analysis

The aim of decision analysis is to support decision makers with information, so that they can make a more founded decision. Thus, decision analysis methods are not used to force a decision, but they are applied for doing a systematic assessment of alternatives, which in many cases does not occur. That is the reason, why a decision process is more valuable as the answer itself.[124]

Decision analysis uses a systematic methodology, which allows one to investigate technologies with their characteristics by defined criteria. Through the provided information of the process, technologies can be compared.[125]

A frequent problem is that in most cases no superior leader can be found and that a few criteria are tradable (e.g. return and risk). Nevertheless, the decision analysis process helps at least to rank all alternatives.[126]

Table 11 shows a list of techniques for doing a decision analysis in TA. It is important to understand the respective analysis tool in detail, as otherwise the result of the decision analysis is not comprehensible and arguable. A final decision is not made only because of the assessment result. The result only serves as an additional information for decision makers and as a basis for a discussion.[127]

Table 11: Methods and tools for decision analysis[128]

DECISION ANALYSIS
Multicriteria Decision Making
Multi Attribute Utility Theory
Scoring
Group Decision Support Systems (Delphi, Analytic Hierarchy Process, Q-Sort)
Decision Trees
Fuzzy Logics

[124] Cf. Henriksen (1997), p.621-622
[125] ibidem
[126] ibidem
[127] Cf. Haag et al. (2011), p.363
[128] Cf. Henriksen (1997), p.618; Cf. Decker/Ladikas (2004), p.29-32; Cf. Wellensiek et al. (2011), p.150-151; Cf. Haag et al. (2011), p.312

3.5 Assessment Approaches

Supplementary to the single TA tools and methods, assessment approaches for evaluating technologies have been developed in the past. These approaches combine issues of different single TA methods from the chapters 3.1 to 3.4 to one overall assessment approach. The following two subchapters introduce the TA approach from the Fraunhofer Institute and the technology risk matrix approach developed by Mankins.

3.5.1 Fraunhofer Project

Aim of the Fraunhofer Institute is to develop appropriate methods and tools, which are able to support research institutions and organizations by identifying systematically and purposefully relevant technology markets, and how to enter them afterwards. Therefore, the Fraunhofer Project provides six methods, which overall objective is to support technology and product developers by identifying relevant technology markets by anticipating prevalent market conditions and by aiding to penetrate the market.[129]

Each method of the Fraunhofer Project is part of an overall methods portfolio, whereby every method pursues a different central question (see Table 12). These central questions, which are thematically focused for the different methods, are representing the relevant part aspects for achieving the superior aim.[130]

Table 12: Methods and central questions of the Fraunhofer Project[131]

METHODS	CENTRAL QUESTIONS
TechAudit	How to increase the technology development competence systematically?
Technology radar	Which new and relevant technologies are available for the product portfolio?
Resource efficiency analysis	How to find alternative, resource efficient technologies?
Technology compass	How is the maturity level of a technology?

[129] Cf. Warschat et al. (2012), p.7-9
[130] ibidem
[131] ibidem

White-spot-analysis	How to detect application gaps within a technology field with the usage of patent data?
Market explorer	Which new applications fields and hence market potentials are available for technologies?

The listed methods of Table 12 supports technology and research developer to conquer the existing gap among the development of a product or technology and its successful placement on the market. To achieve this target, it is necessary to imply market requirements early. As a result, for developers this raise operational and strategic issues with a high degree of complexity. With the aid of the different thematic focussed Fraunhofer methods, it allows the product or technology developer to deal with only one method and the corresponding central question. But, based on the situation of the organization, if it is appropriate a broader analysis can be conducted.[132]

Although each method can be used independently, the Fraunhofer Institute suggest the application of all methods to get the highest benefit. Moreover, a certain sequence for the usage of the methods is recommended, which is shown in Figure 15.[133]

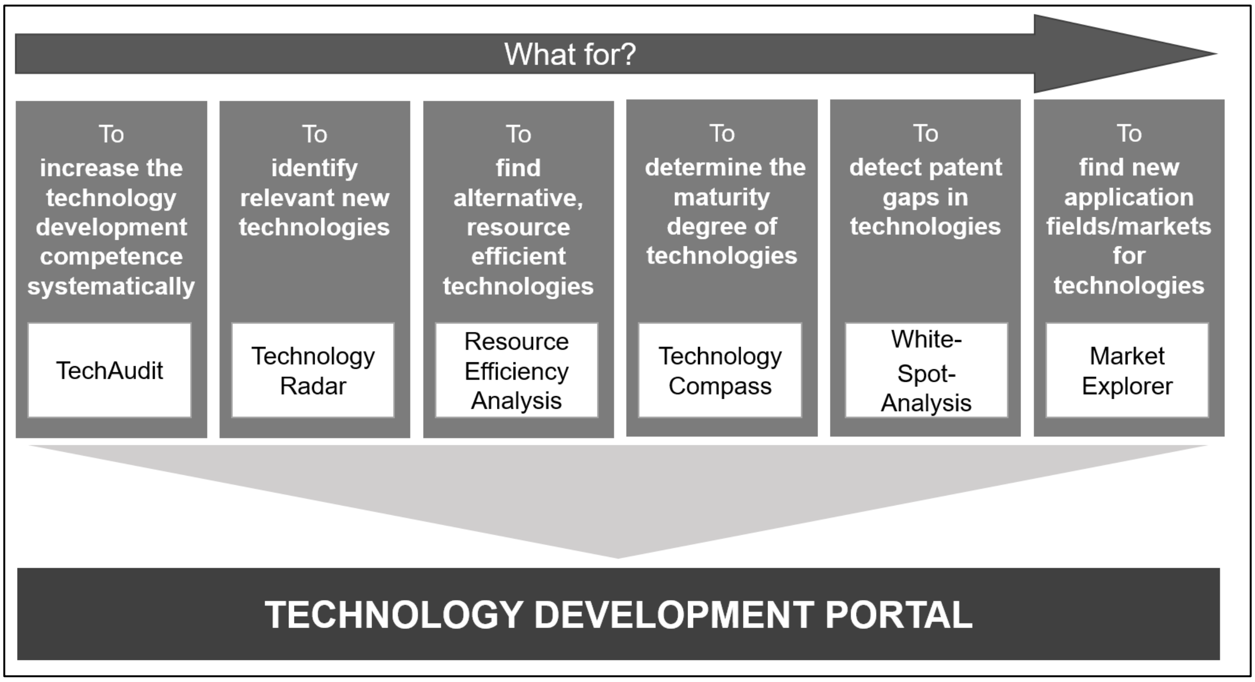

Figure 15: Methods of Fraunhofer Technology Development Portal[134]

[132] Cf. Warschat et al. (2012), p.7-9
[133] ibidem
[134] Cf. Warschat et al. (2012), p.9

TechAudit

The TechAudit poses the beginning of the methods chain. It deals with the investigation of technology development capability of organizations, which is essential for every successful product and technology development[135]. Therefore, the TechAudit process is divided into four stages:[136]

1. Identification of success factors
2. Measurement of success factors
3. Assessment of success factors
4. Increase of success factors characteristics

Dependent on the results of the method conduction, the TechAudit delivers specific recommendations for actions to increase systematically the technology development capability.[137]

Technology Radar

The second step represents the technology radar. This method is an effective and efficient way for early technology detection with the aim of supporting research institutions and organizations timely by identifying relevant technologies and with its evaluation.[138]

The technology radar process is divided into five stages:[139]

1. Technology analysis for firm specific technology need
2. Semantic technology research within visible and invisible internet
3. Technology assessment based on attractiveness and implementation effort
4. Planning of short, medium and long term actions for technology substitution, integration and addition
5. Establishment of a dynamic technology radar for technology research and evaluation in defined intervals

Resource Efficiency Analysis

The third step deals with the resource efficiency analysis. In times with scarcer resources, raising energy prices and a getting worse greenhouse effect, all existing and new developing technologies have to use resources carefully so that they are economically

[135] Cf. Slama/Potinecke (2012), p.54-59
[136] Cf. Slama/Potinecke (2012), p.54
[137] Cf. Warschat et al. (2012), p.9, Cf. Slama/Potinecke (2012), p.54
[138] Cf. Wellensiek et al. (2011), p.118-120; Cf. Ardilio (2012a), p.61-62; Cf. Warschat et al. (2012), p.9
[139] Cf. Ardilio (2012a), p.63-64

acceptable. Thus, the resource efficiency analysis evaluates already in early stages products and technology developments on their potential resource savings.[140]

This stages are structured in:[141]

1. Clarify task by analyzing initial situation and specific requirements
2. Analysis of components and function, identify potential for improvement
3. Find solutions through technology research with the aid of creativity techniques, text mining, data bases, experts
4. Evaluate solutions according to functionality, resource efficiency and profitability
5. Consolidation of results and derive actions for most suitable solution

Technology Compass

The fourth step uses the technology compass method. To evaluate if an investment in a new technology is rational, research institutions and organizations ground their decision on the level of maturity of a technology and its potential for improvement. Based on indicator supported and quantitative comparison of technology developments, the technology compass allows one to determine these criteria.[142]

The main stages of the technology compass process are divided in:[143]

1. Definition of a technology
2. Choose reference technology with a similar structure
3. Define collections of development indicators for both technologies
4. Determination of value processes for both technologies with the aid of journals, web sites, data bases
5. Pairing of analog indicators
6. Comparative analysis of value processes

White-Spot Analysis

The fifth method represents the white-spot analysis. This method analyses and evaluates systematically and efficiently the patent environment of planned technology and product developments. Additionally, this tool delivers information of existing competitor technologies as well as available research potentials and its economic relevance.[144]

[140] Cf. Schuh et al. (2011c), p.171-176; Cf. Warschat et al. (2012), p.10; Cf. Schnabel/Rist (2012), p.75-81
[141] Cf. Schnabel/Rist (2012), p.82
[142] Cf. Mankins (2009a), p.1210-1211; Cf. Warschat et al. (2012), p.10; Cf. Schuh et al. (2011a), p.273
[143] Cf. Knaf/Bügel (2012), p.98
[144] Cf. Wellensiek et al. (2011), p.160-163; Cf. Warschat et al. (2012), p.10

The white-spot analysis process is structured in:[145]

1. Define search criteria for patent research
2. Extract of content with the aid of text mining
3. Identification of white-spots with the usage of a problem solving matrix
4. Analysis of white-spots through assessment criteria (qualitative and quantitative), analysis concerning technical, market oriented and firm related issues
5. Rank white-spots and visualize with a portfolio
6. Utilization of results

Market Explorer

The final method of the Fraunhofer Project is the market explorer. Target of this method is to identify new application fields for present and in the future developed products and technologies. Based on the identified applicability, a forecast concerning potential capitalization opportunities is given to the product and technology developers.[146]

To identify technology markets, the following levels have always to be central for the entire research and assessment process:[147]

- Market: established as well as new potential markets
- Technology: existing as well as new potential technologies
- Technology competition: direct and indirect competitor

The market explorer method is divided in following stages:[148]

1. Technology analysis concerning function, attributes and characteristics
2. Technology competition analysis concerning identified functions and attributes
3. Application analysis for established and new markets, requirement profiles are created based on identified potential markets and applications

[145] Cf. Siwczyk (2012), p.111
[146] Cf. Warschat et al. (2012), p.10; Cf. Kotler/Keller (2016), p.62-75; Cf. Schuh et al. (2011c), p.171-186
[147] Cf. Ardilio (2012b), p.128
[148] Cf. Ardilio (2012b), p.129

3.5.2 Technology Risk Matrix

Another approach called technology risk matrix (TRM) has been developed by Mankins, an expert in space systems and in technology innovation[149]. His approach combines already existing methods to evaluate the technology readiness and the potential risk which could occur[150]. Therefore, the approach is based on three parameters, which have to be taken in consideration, before doing a technology investment:[151]

- **Technology Readiness Level (TRL)**
  What is the level of maturity of a technology?

- **Research and Development Degree of Difficulty (R&D³)**
  How hard is it to achieve from a current TRL the next higher one?

- **Technology Need Value (TNV)**
  How important is the technology for the objectives of an enterprise?

Although the focus for technology readiness and risk assessment (TRRA) lies on key parameters for technical performance and how to increase it with R&D effort, an overall TRRA process must also include the parameters of TRL, R&D³ and TNV. These three parameters allow technologists, system developers and senior managers to communicate in an own language regarding technology investment decisions, independent of a specific technology.[152]

Technology Readiness Level

The TRL was developed by the National Aeronautics and Space Administration (NASA) in the mid-1970s and has been used on-and-off for space technology planning[153]. Nowadays, the TRL has already been adopted by the United States (U.S.), by industries and its usage is also increasing international. The main goal of the TRLs is to measure the maturity level of a technology for making an informed choice of its usage.[154]

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149 Cf. www.artemisinnovation.com (11.01.2017)
150 Cf. Mankins (2009a), p.1208
151 Cf. Mankins (2009a), p.1209-1210
152 ibidem
153 Cf. Mankins (2009b), p.1, Cf. Mankins (1995), p.1
154 Cf. Mankins (2009a), p.1210; Cf. Schulte-Gehrmann et al. (2011), p.71; Cf. Schuh et al. (2011a), p.269,273

Figure 16 illustrates the metric scale (1-9) of the TRL. The lower levels 1-3 include observing basic principles, formulating of a technology concept and testing of proof-of-concept of a technology. In the levels 4-6, the component or the already existing system are validated in laboratory and in relevant environment. Final levels 7-9 deal with the completed system demonstration and with the successful usage in its planned environment. The determination of the TRL is necessary to create the TRM afterwards.[155]

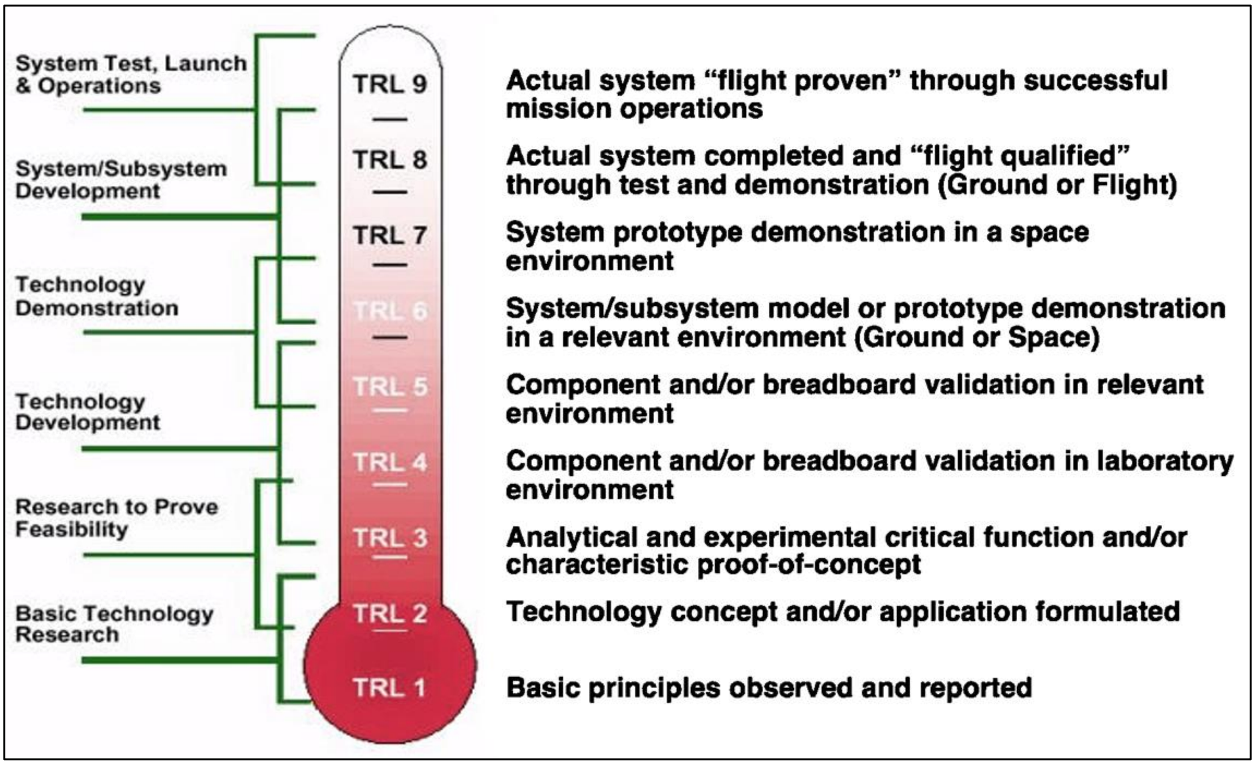

Figure 16: Technology readiness level scale[156]

Research and Development Degree of Difficulty

In addition to the TRL measurement, the R&D³ addresses how hard it will be to move from one TRL to the next higher one and to achieve the objectives of R&D eventually. This parameter is introduced, since the TRL gives no insight of progressing from one level to the next one. The metric scale of R&D³ (1-5) describes the probability that R&D effort in new technologies will fail or succeed (see Figure 17). Whereas a R&D³ value of 1 means that R&D success is very likely, a R&D³ value of 5 expects not to have a realistic chance to have one, since a fundamental breakthrough for this technology would be required.[157]

[155] Cf. Mankins (2009a), p.1211, Cf. Mankins (1995), p.1
[156] Mankins (2009a), p.1211
[157] Cf. Mankins (2009a), p.1210-1211, Cf. Mankins (1998), p.1

The y-axis in Figure 17 represents the probability percentage of R&D success. Each R&D³ value goes along with a corresponding probability percentage, which is used for the TRM afterwards. Moreover, a short definition to each R&D³ value is given.[158]

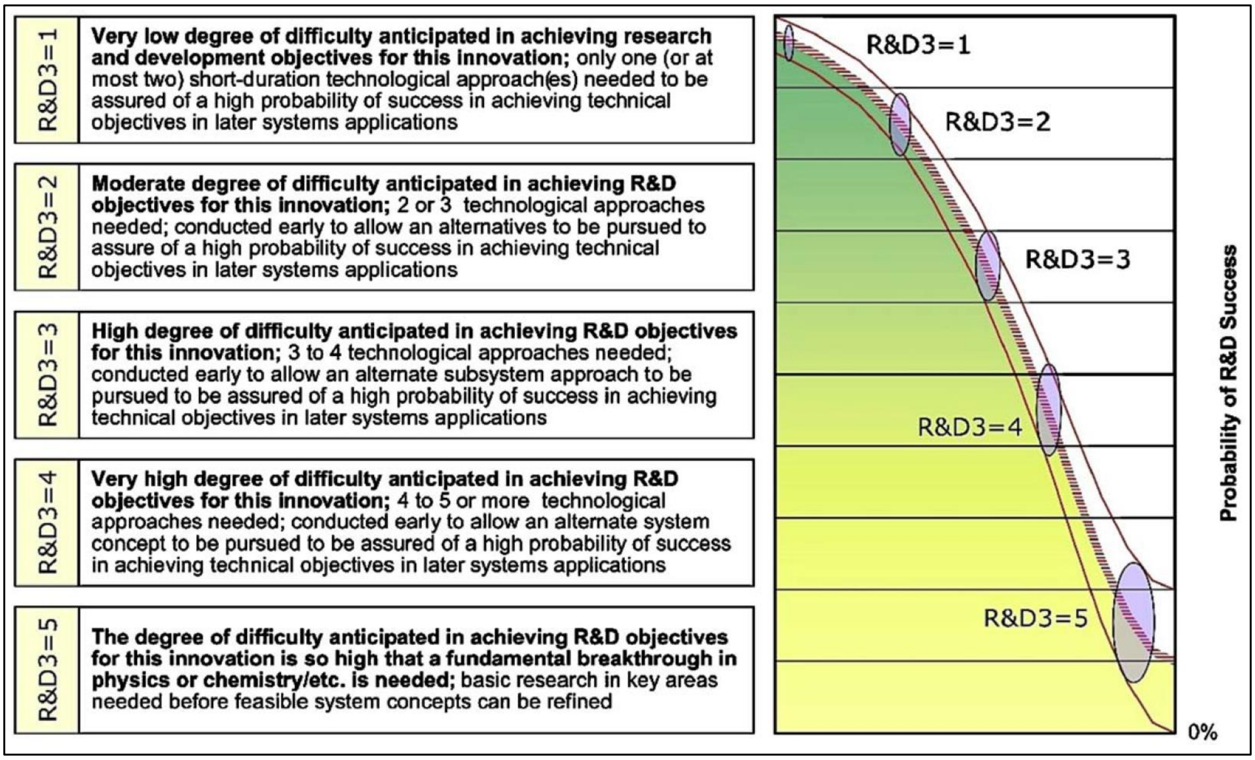

Figure 17: Research and development degree of difficulty scale[159]

Technology Need Value

The last introduced parameter is the TNV. Neither TRL nor R&D³ discuss the need for a new technology. Although TRL and R&D³ are important to assess the technology itself, the understanding for the future application of a technology is essential for a good R&D management. Figure 18 illustrates the scale of the TNV and provides also a short definition to each value. Same as for the R&D³ scale, the TNVs have also a metric scale from 1-5 with a corresponding weighting factor. This factor gives information about the importance and need of a particular technology. Whereas a TNV of 1 implies that technology effort is not critical for success, a TNV of 5 means that the technology is critically important for having one. Again, the TNV is necessary for the creation of the TRM.[160]

[158] Cf. Mankins (2009a), p.1210-1211
[159] Mankins (2009a), p.1211
[160] Cf. Mankins (2009a), p.1210-1211

Technology Need Value	Weighting Factor	Description
TNV-1	40%	The technology effort is **not critical at this time** to the success of the program— the advances to be achieved are useful for some cost improvements; However, the information to be provided is not needed for management decisions until the far- term
TNV-2	60%	The technology effort is **useful** to the success of the program—the advances to be achieved would meaningfully improve cost and/or performance; However, the information to be provided is not needed for management decisions until the mid- to far- term
TNV-3	80%	The technology effort is **important** to the success of the program—the advances to be achieved are important for performance and/or cost objectives AND the information to be provided is needed for management decisions in the near- to mid- term
TNV-4	100%	The technology effort is **very important** to the success of the program; the advances to be achieved are enabling for cost goals and/or important for performance objectives AND the information to be provided would be highly valuable for near-term management decisions
TNV-5	120%	The technology effort is **critically important** to the success of the program at present—the performance advances to be achieved are enabling AND the information to be provided is essential for near-term management decisions

Figure 18: Technology need values[161]

Technology Risk Matrix

All discussed parameters (TRL, R&D³ and TNV) are the fundament of the TA approach by Mankins – the technology risk matrix (see Figure 19). The y-axis represents the probability if R&D effort fails or succeed (R&D³ of Figure 17), the x-axis reflects the consequences of failure or success (Δ-TRL x TNV), where Δ-TRL is the difference between the current and desired TRL before starting with system development, and TNV is the already mentioned weighting factor of Figure 18.[162]

Compared to typical risk matrices, where each technical risk is strictly stated to the technology, this approach uses the equation *Δ-TRL x TNV* to describe the consequences which can occur. With the aid of this approach, the TRM allows to summarize diverse technology risk areas and to compare them afterwards within it.[163]

After determining TRL, R&D³ and TNV of a technology, this technology is placed in the TRM. If a technology has a high probability of R&D failure, and the consequences of R&D failure are also high, the technology would then be plotted in the right upper corner (red

[161] Mankins (2009a), p.1212
[162] Cf. Mankins (2009a), p.1212
[163] ibidem

area). Reversely, a technology with a low probability of R&D failure and consequence of R&D failure would be placed in the bottom left corner (green area). The final aim of this TA process is to evaluate all relevant technologies and to place them in the matrix afterwards. Through the thorough assessment process, a lot of information to each technology is gathered and allows in this way to make a well-informed investment decision.[164]

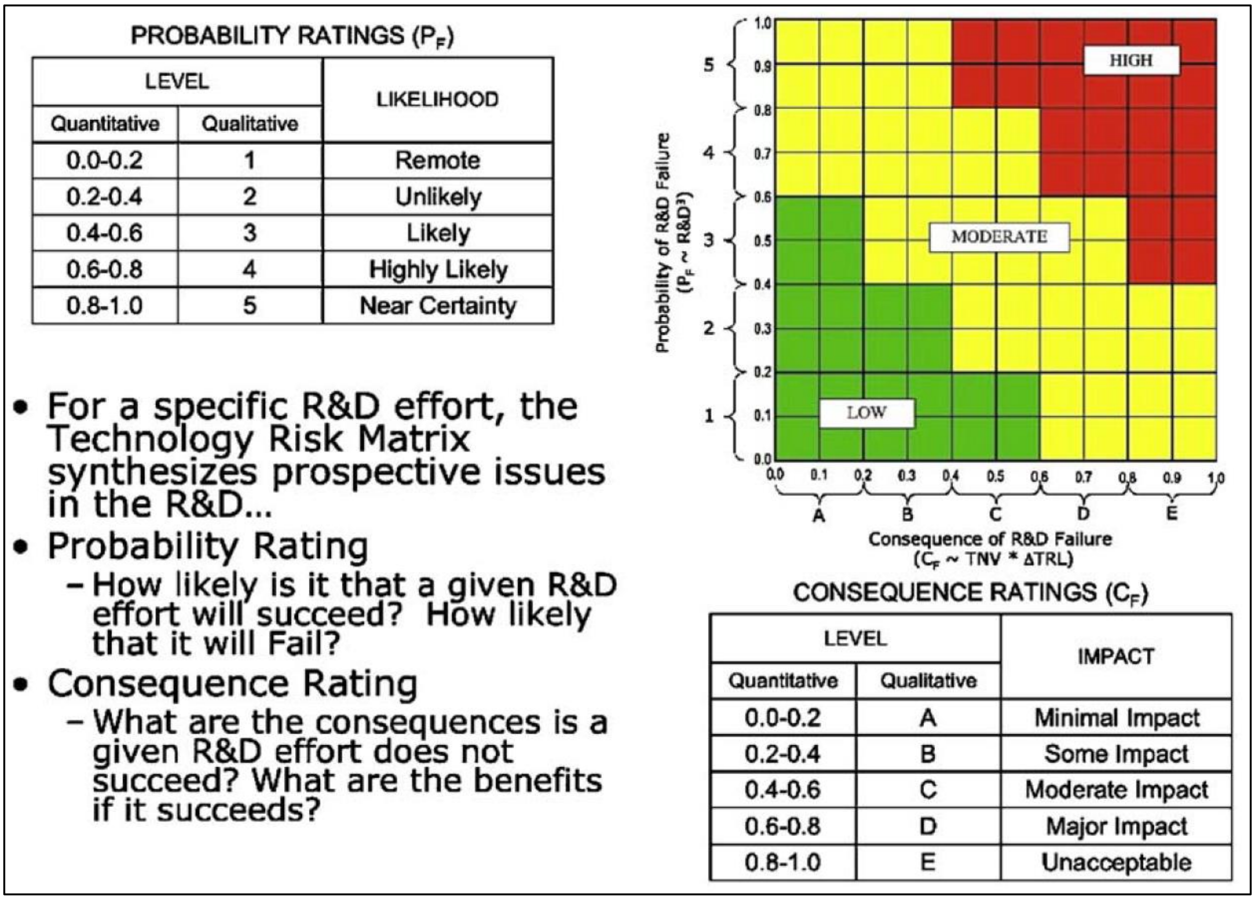

Figure 19: Technology risk matrix[165]

[164] Cf. Mankins (2009a), p.1212-1213
[165] Mankins (2009a), p.1213

3.5.3 Limitations from State of the Art Assessment Approaches

The introduced TA approach in chapter 3.5.1 of the Fraunhofer Institute as well as the technology risk matrix approach by Mankins in chapter 3.5.2 represent two different opportunities to evaluate new technologies. Although these approaches are based on well-founded knowledge of reputable institutions and people regarding TA, both approaches are theoretically drafted yet and partly still in development stage and therefore not applied in practice by now. Moreover, these approaches are designed for the overall technology management within firms and do not fulfill the needs of an investor, who is mostly interested only in an investment recommendation of a technology with potential and not in how to deal with technologies in general.

Further disadvantages of the previous mentioned TA approaches:

- Difficult to get the specific, relevant and necessary information to conduct assessment (e.g. TechAudit, technology radar, market explorer, TRL, TNV, R&D[3])
- Both approaches consume a lot of time for evaluation through applying many different tasks within the stages and to do the relevant and specific data gathering to conduct the evaluation at all
- The approaches are sophisticated and include a various of intricate methods and are therefore tough to understand for the investor
- The investor loses the overview about the assessment process easily
- There is no steering option for the investor which allows to bring in own knowledge and interests
- The investor has to be an expert in TA to understand and to handle these approaches and to achieve the expected outcome
- The Fraunhofer Project is currently only available for Fraunhofer Institutions and therefore not accessible for the investor

Based on the mentioned disadvantages, there is a need for a more practical TA process for an investor. The stages of technology management with their corresponding tasks are designed to satisfy the needs of companies. Potential technology investors desire for an easy manageable TA process, which needs less time for evaluation and gives them also an insight about how it works. As a result, investment decisions should become more transparency and easier to make for investors in the future.

The following chapter 4 discusses a more practical oriented TA process for investors. This process has been developed on the basis of the literature approaches by the Fraunhofer Institute and by Mankins and tries to eliminate their disadvantages and to focus on the investors' needs.

4 Developed Assessment Approach

This chapter deals with the development of an assessment approach for an investor for evaluating the potential of technologies in an effective and timesaving way. The overall aim is to assess and filter technologies for detecting these technologies out of the mass, which may have the biggest potential and influence in the future and are worth an investment. Therefore, a 3-step assessment approach has been developed to achieve these objectives.

Figure 20 illustrates the overall assessment process and its structure divided into the three steps of:

- Pre-filtering of technologies
- Portfolio pre-assessment of technologies
- Detailed technology assessment

These three steps serve also as the respective main sub chapters 4.1 - 4.3 for the ongoing thesis. Detailed information regarding the evaluation process in each step with the defined assessment criteria is given there.

Technology management process integration

Compared to the introduced technology management (TM) process for firms in chapter 2, this new assessment approach can be integrated in the two stages of technology early detection and technology planning. The developed approach deals with the basic tasks and focus areas of these two stages.

Technology catalog

As already mentioned in chapter 1.4, research limitations for the thesis are set. The Institute of Innovation and Industrial Management provided technologies, which could have success in the future. These technologies are collected in a so-called “technology catalog” and serve as input for the developed assessment approach (see Figure 20). All technologies are listed in detail in Appendix A. The structure of the technology catalog with given examples from the catalog of Appendix A is as follows:

- Category of technology (e.g. energy generation or nano technology)
- Technology name (e.g. low-head-hydro power or nano crystal catalyst)
- Current application of technology (e.g. gorlov turbine or hydrogen production)
- Source (e.g. web scientific data base “science direct” or web page “interesting engineering”)
- Publication year
- URL/abstract

3-step assessment approach

Based on the available information from the technology catalog to each technology, the objective of the approach is to evaluate these technologies by appropriate assessment criteria within each step. Hence, the number of technologies are reduced continuously within each step, which could be worth an investment in the end (see Figure 20).

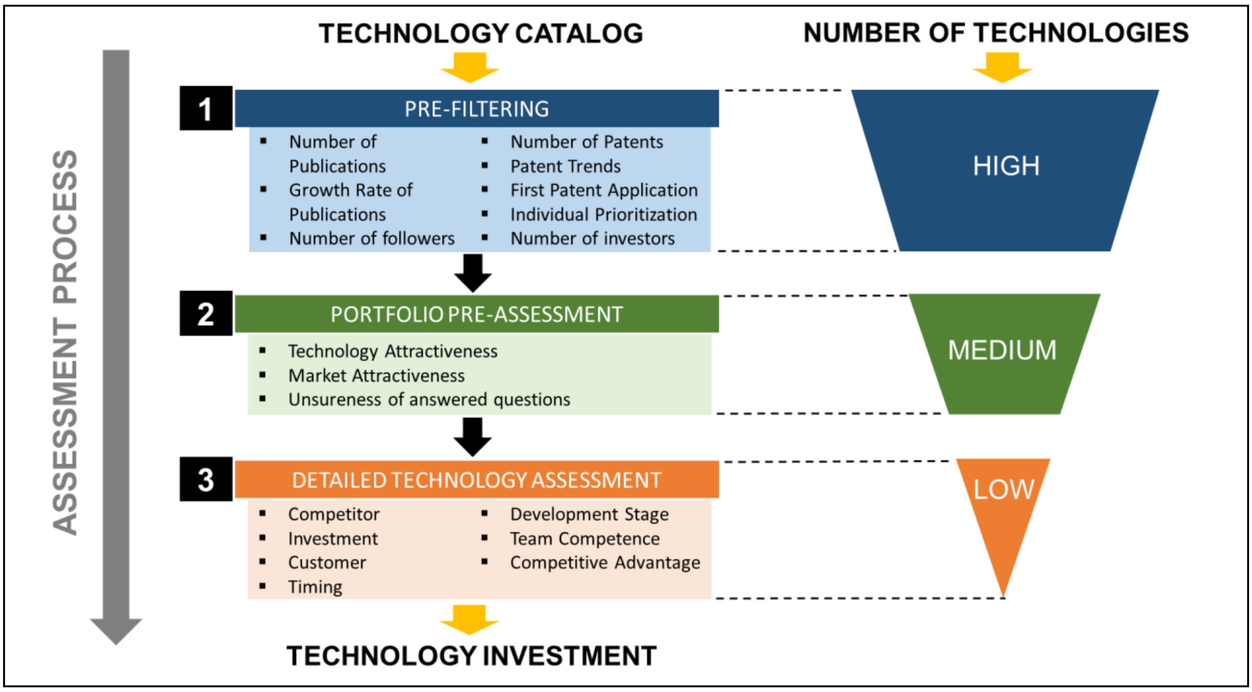

Figure 20: 3-step developed assessment approach[166]

Next, a short overview of the content and the purpose of each of the three assessment steps are given:

1. **Pre-filtering**

   As illustrated in Figure 20, the "pre-filtering" step within the process deals with all technologies from the technology catalog. Based on defined assessment criteria like patent trends or the number of publications of previous years, the objective is to detect extraordinary technologies and to split them from uninteresting ones and hence reduce the number of technologies for continuing their assessment with step 2. As a result, the technologies are filtered and sorted based on their assessment. More details on how the evaluation process works and where evaluation data can be found is discussed in chapter 4.1.

[166] Own presentation

2. **Portfolio pre-assessment**
   Followed by the pre-filtering process, this step uses the identified technologies of step 1 with the best estimated potential and conducts a portfolio analysis for each technology. Due to an evaluation regarding technology attractiveness (TAT) and market attractiveness (MAT), the best evaluated technologies are chosen for a detailed technology assessment in step 3. Further details to the evaluation process and the defined assessment criteria are debated in chapter 4.2.

3. **Detailed technology assessment**
   After the best evaluated technologies from step 2 have been chosen, a separate detailed evaluation of each technology including criteria such as listing the main competitors who are applying this technology, showing who are their customers or in what development stage the product with the applied technology actually is, is conducted. The objective of this step is to get aware about the competitiveness on the market and to demonstrate in form of a competitor table, which competitor the best option for a potential investment would be. More information to this evaluation step is provided through chapter 4.3.

The introduced assessment approach is based on the approaches of the Fraunhofer Project and the technology risk matrix by Mankins by using their assessment focus areas and by adding additional evaluation methods. The new developed approach applies qualitative methods (e.g. opinion of experts) as well as quantitative methods (e.g. analyze patent statistics). Compared to the previous mentioned assessment approaches, the investor has a steering option to filter technologies based on his own preferences and interests, and also quantitative results by evaluating each defined criterion.

Detailed overview of the assessment process

Figure 21 shows a more detailed overview of the overall assessment process to get a better understanding of how the process works. Each of the 11 steps in the process has its own task to fulfill for detecting technologies with potential in the end. The corresponding task of each step is found in Figure 21. Besides the task, examples to each step such as which evaluation criteria are used or what methods for data gathering are applied are listed.

The detailed overview of the assessment process of Figure 21 can be also integrated in the rough overview of Figure 20. Through using the step numbers, following allocation is achieved:

- **Step number 1-3**
  These steps and their corresponding tasks belong to the pre-filtering process and represents the main issues within it.

- **Step number 4-8**
  These steps are part of the portfolio pre-assessment and demonstrates the sequence of how the portfolio is conducted.

- **Step number 9**
  The step number 9 belongs to the detailed technology assessment and analyses separately the chosen technologies.

The step numbers 10 and 11 are not part of the integration of the actual assessment process, but are important for the investor for making a decision in the end. Their content and purpose is as follows:

- **Step number 10**
  This number represents the issue, if after the detailed technology assessment of each chosen technology an investment in a few or all of them is not rational anymore, other technologies from the portfolio with a relative high potential for being successful can be chosen and step number 9 conducted again. Thus, this step serves as checkpoint if appropriate investment opportunities are detected and as loop for choosing other technologies otherwise. It is important to note that the use of the loop is only an additional option, but not mandatory to take.

- **Step number 11**
  If technologies for an investment are identified in the steps 9 and 10 and there is still the willingness to be part of it, the last step implements investment negotiations between the investor and the owner of the technology (competitor). The ideal output is a final decision to invest and to make money eventually.

The following sub chapters are discussing the pre-filtering, the portfolio pre-assessment and the detailed technology assessment more in detail. Each sub process’s criteria and information sources are listed and the evaluation procedure described in form of an example.

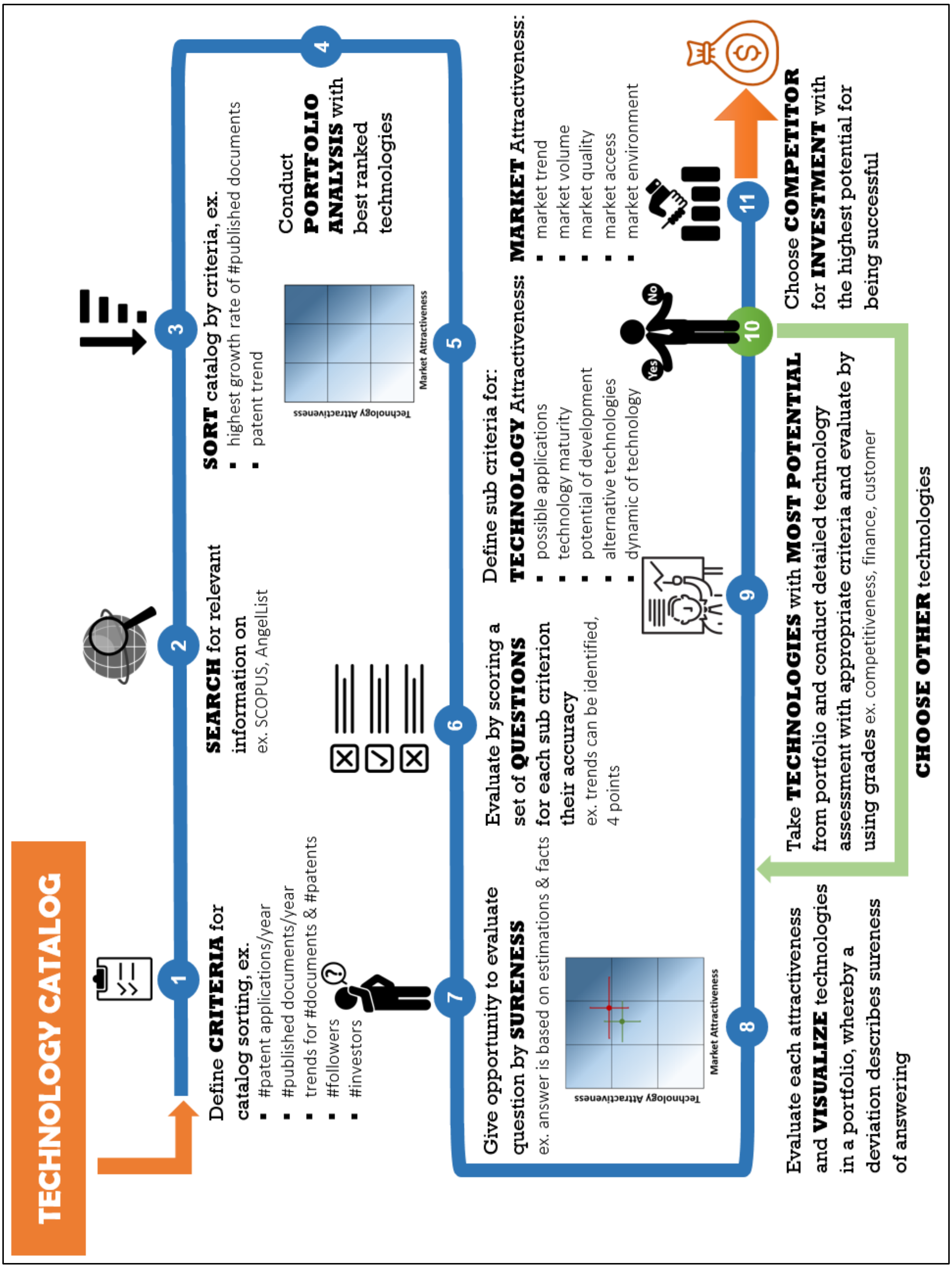

Figure 21: Overview of assessment approach sequence[167]

[167] Own presentation

4.1 Pre-Filtering

The first stage of the 3-step approach is the pre-filtering process of technologies. Its overall aim is to identify novel technologies and to separate them from uninteresting ones. Therefore, an implicit objective is to reduce the number of technologies for continuing with the portfolio pre-assessment afterwards, which is discussed in chapter 4.2.

Before the start of the development of the process, necessary requirements for the process are stated. The following requirements are set:

- Analysis of technologies mostly with quantitative instead of qualitative methods
- Possibility of evaluation of a high number of technologies
- The analysis should be compact and not consume a lot of time
- The evaluation procedure should be easily manageable and understandable for the future user
- The evaluation results have to be transparent and comprehensible
- A free access to information sources should be available
- A common software for the analysis should be used

In addition to the requirements, a list of further aims and the actual purpose of the pre-filtering process are defined. The following aims are set:

- To filter and sort technologies based on their evaluation results
- To reduce the number of technologies by detecting only technologies with a high potential for being successful for continuing with a more exact evaluation afterwards
- To identify trends and demands for certain technology fields
- To offer qualitative steering options for the user
- Visualization of the assessment results

Input for the pre-filtering process

As input for the ongoing pre-filtering evaluation serves the technology catalog explained in chapter 4. The catalog includes 100 technologies, which could have success in the future and aids as data basis and as “test technologies” for developing the process. It is important to mention that hundreds of technologies can be used for the pre-filtering process, but that for the process development stage 100 technologies are sufficient. Therefore, the pre-filtering process is designed to use all available information from the catalog to evaluate each technology entry.

Output of the pre-filtering process

The output of the process is defined by providing the best evaluated and sorted technologies for continuing the evaluation process by conducting a portfolio pre-assessment. The output of the pre-filtering stage serves then as input for the portfolio pre-assessment.

The following sub chapters are dealing with the evaluation criteria and how the corresponding necessary information is collected. Moreover, the filter and sort procedure is discussed in detail. The chapter ends by describing how the pre-filtering tool is used and how the results are visualized within a dashboard.

4.1.1 Criteria for Pre-Filtering Process

This chapter discusses the evaluation criteria of the process and how each criterion is defined. All listed criteria can be used to sort and filter technologies by the corresponding evaluation result, but the sorting can also be applied just by the category of the technology (e.g. energy generation or mobility).

According to Wellensiek, the stage of early technology detection implies methods which integrate the customer view, the supplier view, the competitiveness view and the scientific view. Since this assessment approach is designed for an investor and not for a firm, the view of customers and suppliers are not relevant and only the scientific and competitiveness view are taken to define assessment criteria. To evaluate the competitiveness view, analyses of R&D budgets and projects are conducted. For the assessment of the scientific view, publications and patents frequency analyses are used. Through the use of publications and patents frequency analyses, current relevant research areas can be detected. The assumption is made that the number of publications of scientific documents and patents applications correlates with the research intensity of a research area. Therefore, there is a probability that a new technology will be developed within this research area. The overall aim of each analysis is to identify technology trends.[168]

The following criteria are derived and applied for the pre-filtering process:[169]

- **Number of published scientific documents per year**
  This criterion lists the number of published scientific documents for each year (e.g. 2012-2016) from an existing web platform. Based on the amount of documents in

[168] Cf. Wellensiek et al. (2011), p.150-151
[169] Cf. Wellensiek et al. (2011), p.150-163

the respective year, an increasing or decreasing trend visualization in form of trend lines or bars is illustrated.

- **Growth rate of published scientific documents**
  Due to the data of an existing web platform which provide the number of scientific documents published for each year, a growth rate according to equation (1) is calculated. Therefore, a time horizon of four years (2012-2015) is defined. The result delivers either an increasing or decreasing trend for the technology and hence allows the user to derive actions for keeping the technology or for sorting it out.

  Parameters for the calculation:
  #documents 2015 Number of published documents in 2015
  #documents 2012 Number of published documents in 2012

$$growth\ rate\ [\%] = \left(\frac{\#documents\ 2015 - \#documents\ 2012}{\#documents\ 2012}\right) \times 100 \qquad (1)$$

- **Number of worldwide patent applications per year**
  Similar to the criterion which provides information about the amount of published scientific documents for each year, this criterion collects the number of worldwide patent applications for a single year from an existing platform. Again, four years are defined as time horizon. Based on the visualized patent trend in form of trend lines or bars, appropriate filter and sorting actions can be set.

- **First patent application**
  The first patent application of a technology can also be used as a filter criterion. It allows to identify, if the technology is a new developed one which offers total new opportunities for enterprises and their market, or if it exists already many years but has not been disruptive so far.

- **Scientific document share compared to previous year**
  One way to identify if a real hype regarding a technology exists, is the scientific document share criterion. This criterion calculates the share of documents of the already completed months of the current year compared to the documents collected of the overall last year (see equation (2)). An example would be if a technology has already reached after half of the current year the same amount of publications of the overall last year, this would demonstrate a promising trend for this technology.

Parameters for the calculation:

current #documents 2016	Current number of published documents in 2016
#documents 2015	Number of published documents in 2015

$$document\ share\ [\%] = \left(\frac{current\ \#documents\ 2016}{\#documents\ 2015}\right) \times 100 \qquad (2)$$

- **Number of startups**
  Another criterion is to identify the number of startups, which are using the technology. The more startups that exist, it can be assumed that the more attractive the technology is, but the more competitive the market is too. However, it is not always possible to find startups for a yet unknown technology, but at least the number of startups in a technology field can be collected to get a better overview about the competiveness within this field.

- **Number of investors**
  A huge number of investors in a certain technology could be an evidence for a technology with high potential. However, the more investors are and hence the higher the overall investment in a technology is, the less attractive the technology is. Again, similar to the number of startup criterion, if no investment information for a certain technology can be found, the overall technology field can be investigated to determine its general investment attractiveness.

- **Number of followers**
  Comparable to the last two criteria, the more followers for a technology, it can be assumed that the higher the technology's potential is, but it gets less attractive for an investment, since already a huge number are aware of its potential. Also here, if no data to the technology itself is found, the number of followers in the technology field can be analyzed.

- **Technology category**
  The last sorting and filter criterion is the technology category itself. Depending on the user's preference, certain technology fields can be favored and set as main parameter for the technology's pre-filtering process.

4.1.2 Information Sources for Pre-Filtering Evaluation

The content of this chapter are the information sources for the pre-filtering process, which are used to collect the relevant data for the defined criteria in chapter 4.1.1. Since the result of an evaluation of a technology is always only as good as the available data, sources are an important factor to be successful. The following two data sources are used to gather the relevant information:

- Scopus[170]
- AngelList[171]

About Scopus and how to handle it

Scopus is a web-based, digital solution of the Elsevier Company currently owned by the RELX Group. Elsevier provides information for solutions that enhance the performance of health, technology professionals and science.[172] Scopus is one of the largest provider of a data base for abstracts and peer reviewed literature of books and scientific journals, collected from research all over the world. Gathered information of Scopus belong to the fields of technology as well as science, medicine, social sciences, and arts and humanities.[173]

The Scopus search platform requires to set inputs by the user to provide one with relevant results afterwards. To get informative and only essential results, the following input parameters have to be defined:[174]

- Search term (e.g. technology name entry from technology catalog)
- Define search field (e.g. abstracts, references or authors)
- Data range (e.g. 2005 – 2016)
- Document type (e.g. articles, books, conference papers or reviews)

The input of the search term has an important influence for the ongoing information output. Scopus’s search algorithm provides only accurate information results, when the whole search term is put in quotation marks. Otherwise, Scopus would deliver information for each word within the search term and hence lead to more but also improper search results. If it is the case that the technology name as search term provides only a few or no search results at all, the technology’s application term from the technology catalog can be used as search term to find the relevant information. Once more, the search term

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[170] www.scopus.com (10.09.2016)
[171] www.angel.co (04.09.2016)
[172] Cf. www.elsevier.com (25.01.2017a)
[173] Cf. www.elsevier.com (25.01.2017b)
[174] www.scopus.com (10.09.2016)

has to put in quotation marks to get more accurate results. If this search term delivers no relevant information results again, then both already used search terms are too specific and have to be changed in a more cursory search term such as the technology category. To guarantee that the same search results are found again, the search term is always noted.

After Scopus has processed the input data, it provides one with information as output regarding:[175]

- The number of relevant documents
- A list of all found documents, which can be viewed and downloaded
- A statistic of the number of documents published for each year
- The number of worldwide patent results
- A statistic of the number of patent applications for each year
- In which year the first patent was issued

The output of the search result serves as basis for the evaluation of the defined pre-filtering criteria in chapter 4.1.1. Table 13 lists the settings which have been chosen for the development of the process.

Table 13: Settings for Scopus search process

PARAMETER	SETTING
Search term	The respective technology name or application
Search field	In article titles, abstracts and keywords
Data range	Between 2012 and 2016
Document type	All

[175] ibidem

About AngelList and how to handle it

The second applied source represents AngelList. This U.S. company is a web based platform for startups launched in January 2010 by Babak Nivi and Naval Ravikant[176]. The platform offers startups opportunities to:[177]

- Raise money online
- To recruit employees
- To apply for funding

Compared to the Scopus platform, AngelList requires as input only a search word for running the search routine. The output offers one results associated with the search word structured in categories of people, companies, markets, locations, roles, skills and colleges[178].

The categories of companies and markets aid the process of filtering and sorting technologies. The analysis of a company provides one information regarding:[179]

- The firm's overview
- The product
- The number of followers
- The current investments and investors
- The team members
- Job offers

Since AngelList rarely finds information to the technology itself as it is in some cases too specific, the market category for a technology field provides more useable results. Hence, the technology field is used as input for the market evaluation of a technology. Thus, the analysis for the market delivers information to:[180]

- The overall number of companies within the field
- The overall number of investors within the field
- The overall number of followers within the field

Additionally, AngelList provides an average pre-money valuation of all companies within a technology field. However, not for all fields a pre-money valuation exists.[181]

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[176] Cf. www.angel.co (04.09.2016)
[177] ibidem
[178] ibidem
[179] ibidem
[180] ibidem
[181] ibidem

4.1.3 Evaluation and Trend Visualization of Technologies

The aim of this chapter is to demonstrate the evaluation procedure of the pre-filtering process. With the aid of the technology “lithium-ion”, the search process of chapter 4.1.2 and the following evaluation of the criteria introduced in chapter 4.1.1 are conducted and visualized afterwards. The example evaluation is divided into three steps:

- **Step 1:** Search for the defined criteria
- **Step 2:** Evaluate criteria
- **Step 3**: Visualize results

Microsoft Excel is used as software to gather all relevant information of step 1 and to evaluate them afterwards in step 2. Moreover, Microsoft Excel is also used to visualize the assessment results in step 3.

Step 1

The first step deals with gathering relevant information for the ongoing evaluation in the second step. As search word, the term “lithium-ion” is used and Scopus provides as output the document (see Table 14) and patent statistic (see Table 15). To get more information about the search settings of Scopus, have a look at the previous chapter (Table 13). Moreover, Scopus noticed the first patent application for “lithium-ion” in the year 1922.

Table 14: Statistic of number of published documents for lithium-ion technology

Year	2012	2013	2014	2015	2016[182]
Number of documents	3208	4270	5598	6547	5620

Table 15: Statistic of number of patent applications for lithium-ion technology

Year	2012	2013	2014	2015	2016[183]
Number of patents	19986	24270	26008	26348	20593

With the assistance of AngelList, an evaluation regarding the number of companies, investors, followers and the average pre-money valuation is conducted. As the technology term “lithium-ion” is too specific for providing meaningful search results, the technology’s overall category, which is provided in the technology catalog as “energy

[182] 2016 includes only the number of published documents until the 4th of November
[183] 2016 includes only the number of published documents until the 4th of November

storage”, has been used as search input at the AngelList platform. Table 16 lists the search results. The average pre-money valuation for energy storage is $5,9 million.

Table 16: AngelList search data for energy storage

Criterion	Companies	Investors	Followers
Number	19986	24270	26008

Step 2

Based on the gathered data of step 1, the values for the criteria growth rate and document share are calculated within this step. Their respective calculated values are interpreted in Figure 23.

The growth rate needs the document data of Table 14 and is calculated for the example lithium-ion technology by using equation (1) to:

$$growth\,rate\;[\%] = \left(\frac{6547 - 3208}{3208}\right) \times 100 = 104$$

In addition, the document share for the technology lithium-ion is calculated by using again the data of Table 14 but equation (2) now to:

$$document\;share\;[\%] = \left(\frac{5620}{6547}\right) \times 100 = 86$$

Step 3

The last step is the visualization of the evaluation results. As already mentioned, Microsoft Excel is used as software to support the user with the relevant tools.

Microsoft Excel provides functions such as trend lines and trend bars, which are able to generate a trend overview within a cell based on the gathered data such as of Table 14 and Table 15. As a result, it makes it a lot easier for the user to value technologies and their trends only with a short view instead of reading number by number.

To visualize the number of documents for the lithium-ion technology from 2012 - 2015, a trend line to demonstrate their development is used and is shown in Figure 22. Also, trend bars are applied for illustrating the development of the number of patent applications.

SEARCH WORD	TREND #DOCUMENTS 2012-2015	GROWTH RATE 2012-2015	DOCUMENT SHARE 2015-2016	PATENT TREND 2012-2015
lithium-ion		↑ 104%	↗ 86%	
"low head" hydro power		↓ -25%	→ 50%	
inductive vehicle charging		↑ 427%	→ 67%	
3d-printing concrete		↑ 600%	↑ 229%	
"H2 production"		↑ 288%	↗ 88%	
"nano transistors"		↓ -58%	→ 60%	
hydrogen fuelcell		↓ -20%	↓ 25%	
hydrogen fuelcell		↓ -20%	↓ 25%	
"nuclear fusion"		↓ -7%	↗ 78%	
"solar panel"		→ 34%	↗ 77%	
"solar thermoelectric generator"		↑ 200%	→ 56%	
"wind turbine"		→ 7%	↗ 77%	

Figure 22: Evaluation extract of pre-filtering process[184]

As seen in Figure 22, the calculated growth rate and document share are part of the visualization. The colored arrow next to each value is an additional symbol for visualizing potential trends of a technology. A green arrow highlights technologies with a high growth rate over the past four years, whereas a red arrow gives information that a decline for this technology is expected. Figure 23 shows the meaning of each colored arrow more in detail by listing the defined percentage ranges. As a consequence, the results of the calculation are more expressive and more obvious for the user.

symbol	growth rate	document share
↑	> 100%	> 100%
↗	≥ 50% < 100%	≥ 70% < 100%
→	≥ 0% < 50%	≥ 40% < 70%
↓	< 0%	< 40%

Figure 23: Legend of arrows of pre-filtering evaluation[185]

184 Own presentation and calculation
185 Own presentation and definition

4.1.4 Filter and Sort Process

After all available technologies are evaluated by the defined criteria as shown with the example of the lithium-ion technology in chapter 4.1.3, it allows one to sort and filter the technologies based on own preferences. Therefore, this chapter discusses and shows possibilities how it works.

Since a huge amount of data is collected for the evaluation of each technology gathered in an Excel file, the interpretation of the key values becomes complex. Thus, through the application of visualization tools as additional support, it allows the user to get an overview about all evaluation results immediately. An example provides Figure 24, where the best 15 calculated growth rates of technologies are used and visualized with the corresponding patent statistic.

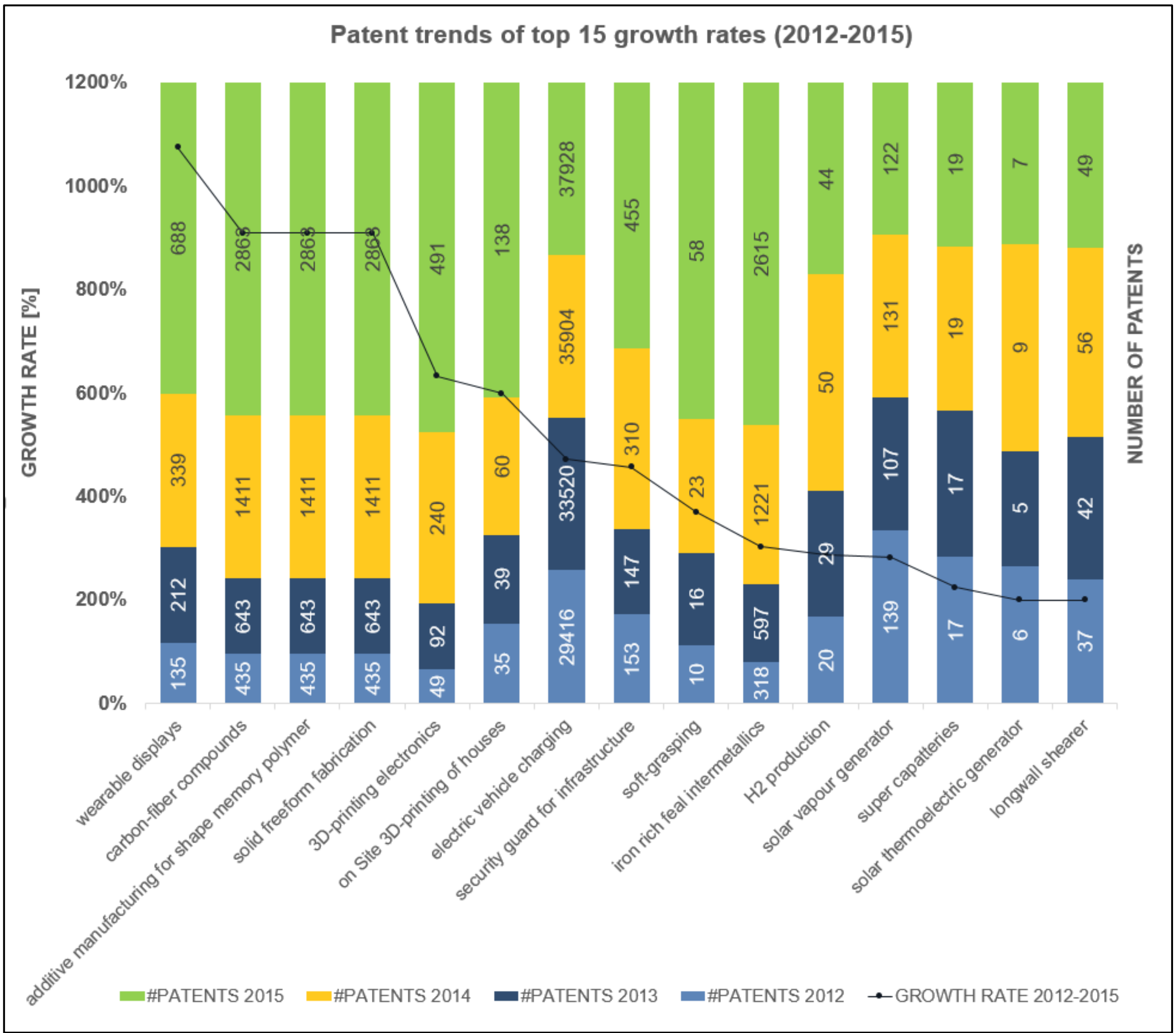

Figure 24: Top 15 growth rates of technologies with their patent statistic[186]

[186] Own presentation and calculation

Basically, all defined criteria of chapter 4.1.1 can be used to sort and filter technologies, but each user of the software chooses first what are the main criteria for their purpose and define their importance order fort sorting the technologies afterwards. Thus, a sort sequence for the ongoing visualization of the evaluation results is defined. As a result, a customized evaluation and visualization platform is generated.

Dashboard

To get an overview about all evaluation results to each technology, a developed dashboard contains linked charts for the defined criteria of chapter 4.1.1, which demonstrate always the current best 15 technologies based on the most important criterion defined by the user before (see Figure 26). In this example of the dashboard, the growth rate criterion is defined as the most important criterion and all technologies are sorted based on it.

Since the sorting order is now already set by the user by defining the most important criterion, the next objective is to filter the technologies to get only these ones, which really have a high potential for being successful and are interesting for the user. The dashboard allows one to filter technologies with the aid of filter buttons by categories, tags and the final "yes or no" decision to decide if the technology should stay in the process (see Figure 25).

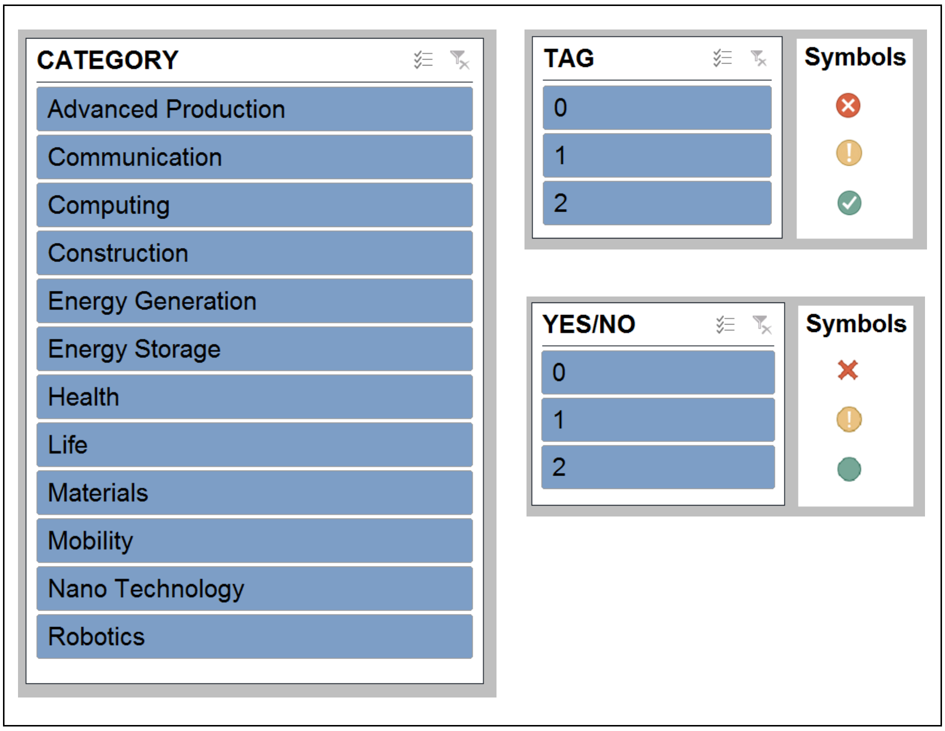

Figure 25: Filter buttons for dashboard[187]

[187187] Own presentation

Filter options "tag" and "yes/no"

The option "tag" allows the user to qualitative pre-evaluate technologies by its own. For this purpose, the Excel pre-filtering file provides a column within the data set, where the user puts in a number of 0, 1 or 2. As a better form of visualization and to make it more obvious within the file, each number is converted to a symbol after the input (see Figure 25). The reason for the use of numbers instead of directly applying the symbols lies in the easier handling for the user within Excel. Table 17 lists the definition for each number's application purpose. Through this option, it allows the user to filter technologies of the dashboard based on the own valuation and preferences. Also, the introduced trend lines and trend bars of Figure 22 are used to pre-evaluate the technology based on quantitative results.

Table 17: Definition of the tag filter

NUMBER	DEFINITION
2	The technology is promising and interesting for the user
1	Partly the technology is promising, partly unpromising; not sure yet
0	There is no interest for the technology; also not a promising one

Additionally, there is the "yes/no" option to filter technologies. This filter works like the tag filter, but compared to it, this one is used to make a final decision regarding to keep or kick technologies after reviewing each technology in detail. Table 18 contains the definition for each number.

Table 18: Definition of yes/no filter

NUMBER	DEFINITION
2	The technology hast a high potential for being successful
1	Not sure yet, if technology will have success in the future
0	There is no probability of success for this technology

It is important to note that all different filters can be applied together, but do not have to. After the filter settings have been selected, every chart within the dashboard is updated automatically with the relevant evaluation results.

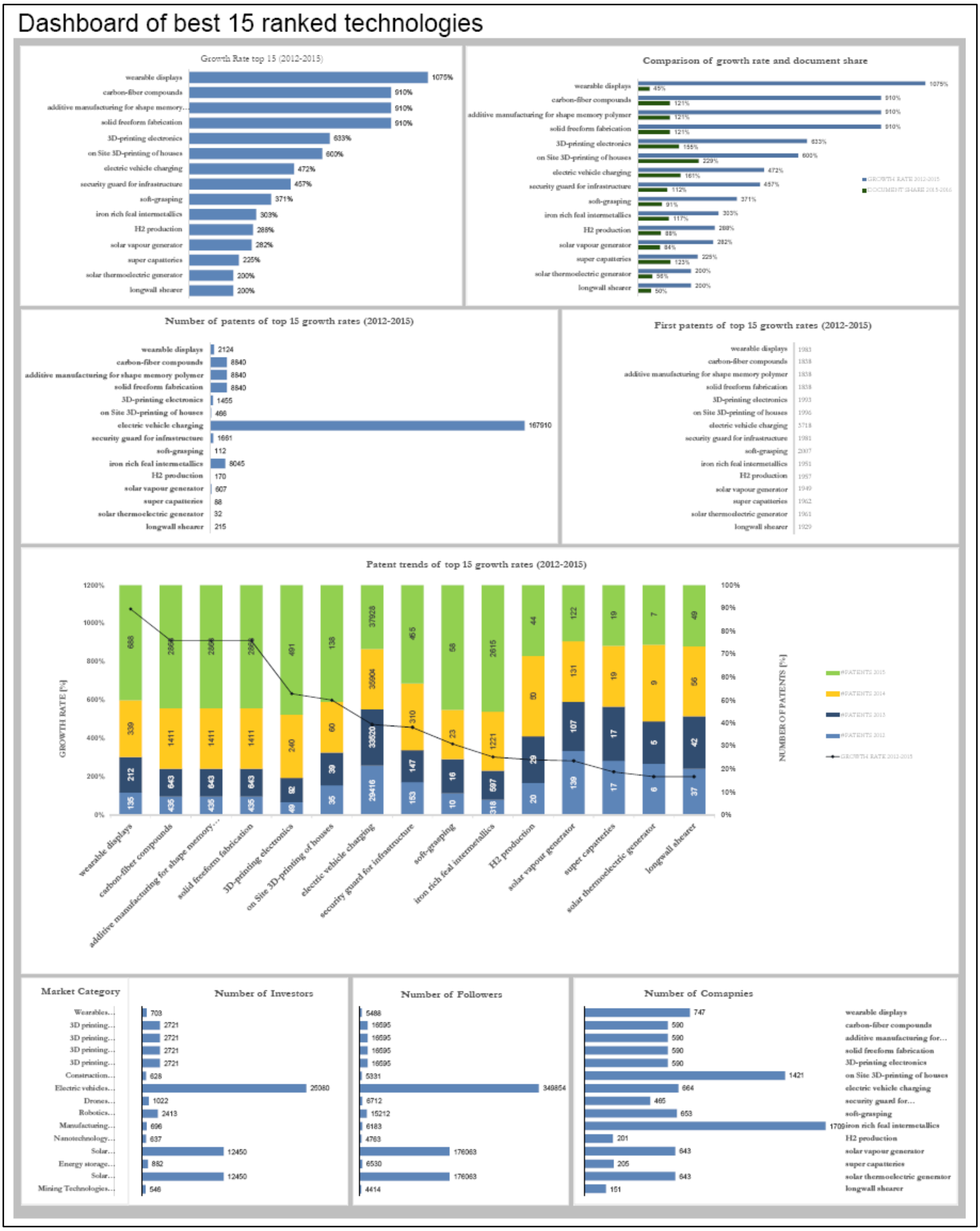

Figure 26: Dashboard of 15 best ranked technologies[188]

188 Own presentation and calculation

4.2 Portfolio Pre-Assessment

The second stage of the 3-step approach is the portfolio pre-assessment process of technologies. Its overall aim is to analyze technologies received from the pre-filtering process of chapter 4.1 more in detail and hence to reduce the number of technologies again. The remaining technologies are used to conduct a detailed technology assessment in the last stage of the process explained in chapter 4.3.

The following requirements for the process development are stated:

- The analysis should again be compact and not consume a lot of time, but should also be more detailed compared to step 1
- Evaluation criteria should be defined, where collecting the necessary data should not be too demanding, but should also include all the necessary information to get an informed assessment result
- Qualitative and quantitative methods should be used
- The evaluation should not be technology field specific
- The procedure of evaluation should be easy applicable and understandable
- The assessment results have to be transparent and comprehensible

Besides the above shown requirements, following objectives for the portfolio pre-assessment are defined:

- To reduce again, but in a more detailed evaluation compared to step 1, the number of technologies which do not have potential for success in the future
- To deliver technologies for a more thorough analysis in a further evaluation stage
- Try to estimate the risk a technology implies
- Visualization of the assessment results

Input for the portfolio pre-assessment process
As input for the ongoing portfolio pre-assessment serves the technologies identified from the pre-filtering process. Already gathered data from the previous process such as patent or document trend statistics can also be used as additional information.

Output of the portfolio pre-assessment process
The output of the portfolio pre-assessment process represents the best estimated technologies, which is discussed in detail in the ongoing stage of the detailed technology assessment. Therefore, the output of this step serves as input for the last one.

Portfolio analysis

Due to the stated requirements and the defined aims of this process, a portfolio analysis is used to evaluate the technologies within this step. Based on the described technology portfolios in chapter 3.4.4, an own portfolio analysis is derived and developed.

According to Bullinger, a portfolio analysis is always based on the following three criteria:[189]

- A criterion which is directly influenced by the firm for the abscissa
- A criterion which is not directly influenced by the firm for the ordinate
- A free chosen criterion which determine the diameter of the bubble

Since this development of a technology assessment approach is generic and not firm and therefore not technology field specific, a criterion which is directly influenced by a firm is not part of the developed technology portfolio analysis. As shown in Figure 27, the portfolio is based on the criteria technology attractiveness (TAT), market attractiveness (MAT) and the unsureness of answered questions, which implies the deviation of the technology evaluation.

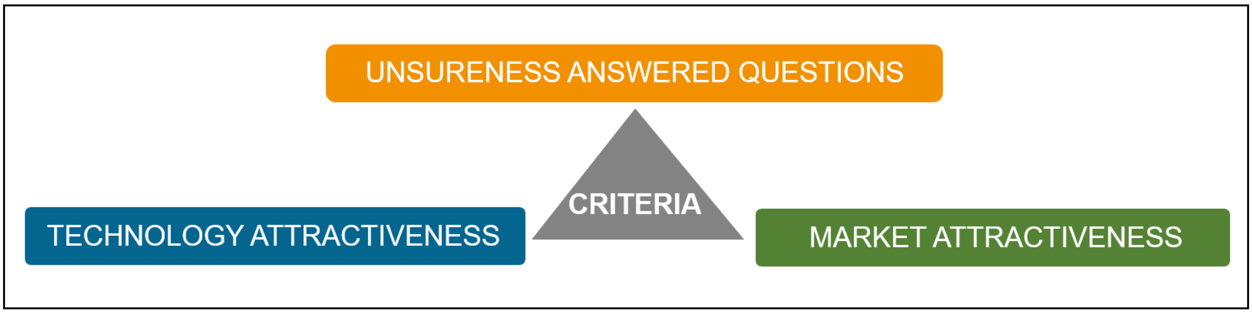

Figure 27: Criteria for portfolio pre-assessment[190]

To determine the technology and market attractiveness for a technology, sub criteria are defined and discussed in the chapters 4.2.1 and 4.2.2. To evaluate every sub criterion of the respective attractiveness, a question set to each sub criterion is given and is evaluated by the user by choosing one of the predefined options of how well each question applies (see chapter 4.2.4). Hence, a corresponding score based on the user's evaluation is derived automatically (see chapter 4.2.5). It is important to note that each sub criterion has a different influence to the respective attractiveness result, since a pairwise comparison is conducted in the chapter 4.2.3 to determine each importance and hence its weighting. Additionally, an opportunity is given to answer each question by how

[189] Cf. Bullinger (1994), p.144
[190] Own presentation

sure the user evaluates the question (e.g. to 100% sure or only to 50%). Thereafter, the unsureness of answered questions criterion is calculated in chapter 4.2.5 based on the certainty of the user's evaluation. After answering all questions, the overall assessment of a technology with its achieved evaluation scores is illustrated in a portfolio.

Microsoft Excel is used as software to conduct the overall portfolio pre-assessment. The Excel file contains all questions to each sub criterion as well as the whole evaluation procedure including criteria weighting and question sureness calculation. Moreover, Microsoft Excel is applied to visualize the assessment results in form of a portfolio eventually.

4.2.1 Technology Attractiveness Criteria

To evaluate the overall technology attractiveness criterion for the portfolio analysis, the criterion is divided into defined sub criteria. Thus, this chapter discusses the defined sub criteria and explain their purpose.

Based on the introduced technology portfolios of chapter 3.4.4 (e.g. McKinsey technology portfolio), recommended indicators to determine the technology attractiveness are taken over. Furthermore, appropriate sub criteria are chosen from the collection of assessment criteria by Schimpf shown in Appendix B. Also, sub criteria are derived from the technology risk matrix approach by Mankins in chapter 3.5.2.

Following sub criteria are used to assess the technology attractiveness:[191]

- **Possible applications**
  The aim of this criterion is to identify if there are multiple options for the usage of the technology. Many possible applications for the technology in potential products increases the attractiveness of the technology and less possible usages decreases the attractiveness, respectively.

- **Technology maturity**
  This criterion determines the maturity of the technology. A more mature technology is more attractive and a less mature technology less attractive, respectively. A differentiation is done according to the introduced TRL in chapter 3.5.2 by evaluating if the technology is just in basic research or already applied in a system for proof of concept.

[191] Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.56-57; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.336; Cf. Henriksen (1997), p.615-633

- **Potential of development**
  The objective of this criterion is to identify the potential of development for a technology. The more R&D institutions, the less complex the technology and inexpensive the infrastructure for R&D is, the more attractive the technology will be. Additionally, a "bottleneck" technology for certain applications increases the attractiveness.

- **Alternative technologies**
  This criterion analyses the competitive situation of a technology. If there are many other technologies available instead of using the evaluated one and technology characteristics do not differ in performance, the technology is less attractive. Moreover, substitution products can decrease the attractiveness.

- **Dynamic of technology**
  The aim of this criterion is to determine the expected lifecycle of the technology, before the technology will be replaced with a new one. The more years for the technology are expected, the more attractive the technology is and vice versa.

Further information to each sub criterion is found in Appendix C. For each sub criterion a set of questions with defined choice options is proposed for evaluation.

4.2.2 Market Attractiveness Criteria

Similar to the previous chapter, this chapter discusses again criteria to evaluate an attractiveness for a technology, but this time for the market. Therefore, to evaluate the overall market attractiveness criterion for the portfolio analysis, the criterion is also divided into defined sub criteria and an explanation for their purpose given.

Recommended indicators to determine the market attractiveness from the introduced technology and market portfolios of chapter 3.4.4 (e.g. BCG portfolio and McKinsey technology portfolio) are used. Again, appropriate sub criteria are applied from the assessment criteria collection by Schimpf listed in Appendix B. Moreover, thoughts of the technology risk matrix approach by Mankins of chapter 3.5.2 are adopted.

Following sub criteria are used to assess the market attractiveness:[192]

- **Market trend**
  The aim of this criterion is to identify, if the demand within a technology area is increasing. A high market trend increases the market attractiveness, whereas a non existing trend decreases the attractiveness. Moreover, a need from the market for a certain technology also increases the attractiveness.

- **Market volume**
  This criterions objective is to investigate, how many potential customers for the usage of the new technology in different products are available. The market attractiveness increases the bigger the market volume is and decreases if only a small market volume is tracked down, respectively.

- **Market quality**
  The aim of this criterion is to analyse the quality of the market. The quality includes investigations to market lifecycle, competitive intensity, bargaining power of the buyer and threats of potential substitution products. A low level of the lifecycle, a non-existing competitive situation, a monopoly and no threats of potential product replacements increases the market attractiveness and vice versa.

- **Market access**
  The objective of this criterion is to find ways for the distribution of the technology. If there are early adopters who are interested in the technology, it leads to an increase of the market attractiveness. Moreover, a low time to market increases the attractiveness as well. If there is only a niche market available for the technology usage, it also increases the attractiveness.

- **Market environment**
  The aim of this criteria is to identify potential problems the market could imply. Bargaining power of suppliers and barriers like legal or environmental issues decreases the attractiveness of the market.

Additional information to each sub criterion can be found in Appendix D. Again, for each sub criterion a set of questions with defined choice options is proposed for evaluation.

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[192] Cf. Bruhn (2001), p.72-73; Cf. Schimpf (2010), p.224-228; Cf. Mankins (2009a), p.1208-1215; Cf. Schimpf/Rummel (2015), p.56-57; Cf. Metze (2008), p.325-346; Cf. Henriksen (1997), p.615-633

4.2.3 Pairwise Comparison of Technology and Market Criteria

Since not all defined sub criteria of chapter 4.2.1 and 4.2.2 are equally important for the evaluation of the overall attractiveness, a pairwise comparison is conducted for the TAT sub criteria as well as for the MAT sub criteria. This step is necessary to bring the criteria in a priority order and to determine their importance weighting.

To conduct a pairwise comparison, a table serves as template where all needed criteria for the evaluation of their importance weighting are part of it. Therefore, the table is filled out with the same criteria vertical as well as horizontal to compare them afterwards. As example serves Figure 28 by listing the sub criteria of the TAT evaluation. Then one start comparing if the criterion within the vertical list is

a) More important (5)
b) Equally important (3)
c) Less important (1)

compared to the criterion within the horizontal list. Hence, the appropriate points are put in the relevant cell. As a criterion cannot be compared with itself, the diagonal of the table stays always blank.[193]

	Possible applications	*Technology maturity*	*Potential of development*	*Alternative technologies*	*Dynamic of technology*	*∑Sum*	*Weighting*
Possible applications		3	5	3	5	16	**26,7%**
Technology maturity	3		3	3	5	14	**23,3%**
Potential of development	1	3		3	3	10	**16,7%**
Alternative technologies	3	3	3		5	14	**23,3%**
Dynamic of technology	1	1	3	1		6	**10,0%**
						60	**100%**

Figure 28: Pairwise comparison of technology attractiveness criteria[194]

[193] Cf. Ophey (2005), p.41-43
[194] Own presentation and calculation

After the table has been fully filled out, all points of each row are summed up. Next, the overall sum of awarded points is calculated by summing up each row sum. As a last step, the importance weighting is calculated by setting each row sum in ratio to the overall awarded points.[195]

A detailed result of how the technology sub criteria are compared is visualized in Figure 28. The corresponding weighting result is illustrated in Figure 29. Whereas the criterion of possible applications is determined as the most important one followed by the maturity and alternative criterion, the criteria for development potential and dynamics of technologies are evaluated as not that important for the overall TAT. The weighting percentages of each sub criterion are used in chapter 4.2.5 to assess the overall TAT.

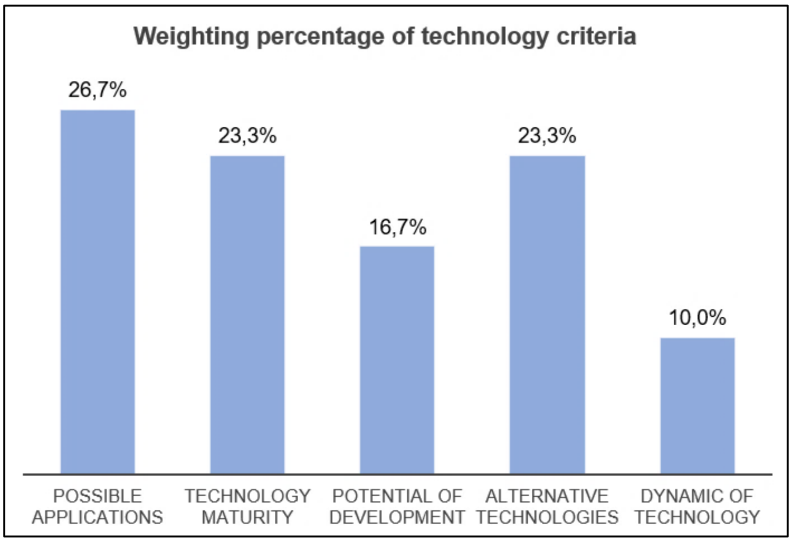

Figure 29: Weighting percentage of technology attractiveness criteria[196]

A pairwise comparison is also conducted for the sub criteria of the MAT. Using the same evaluation methodology as already shown, Figure 30 visualizes the result of the comparison process among the market criteria.

[195] Cf. Ophey (2005), p.41-43
[196] Own presentation and calculation

	Market trend	*Market volume*	*Market quality*	*Market access*	*Market environment*	*∑Sum*	*Weighting*
Market trend		3	3	3	5	14	**23,3%**
Market volume	3		3	1	3	10	**16,7%**
Market quality	3	3		3	3	12	**20,0%**
Market access	3	5	3		3	14	**23,3%**
Market environment	1	3	3	3		10	**16,7%**
						60	*1*

Figure 30: Pairwise comparison market attractiveness criteria[197]

Figure 31 demonstrates the weighting results of the pairwise comparison. The criteria market trend and market access are determined as the most important ones, followed by the market's quality. The market volume and market environment are ranked in a tie on the last position. In chapter 4.2.5 the weighting results are used to examine the MAT evaluation of a technology.

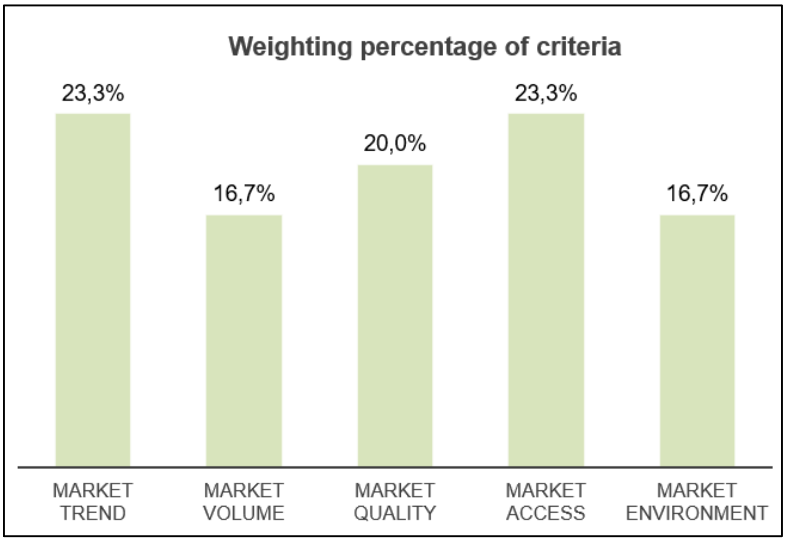

Figure 31: Weighting percentage of market attractiveness criteria[198]

[197] Own presentation and calculation
[198] Own presentation and calculation

4.2.4 Procedure of analyzing defined Technology and Market Criteria

This chapter discusses how each criterion is analyzed, regardless of technology or market attractiveness. Additionally, this chapter serves as basis for how the criteria are evaluated in chapter 4.2.5 afterwards. To show how the analyzing procedure works, the sub criterion “possible applications” is chosen to demonstrate it.

For each sub criterion a set of questions is available, which has to be evaluated by the user. Each question set builds up on main questions and side questions, but a differentiation of them is not recognizable for the user. Therefore, each question has a question weighting within the set for the ongoing evaluation in chapter 4.2.5. For each question five answer options are already pre-defined by the developer. The user has to choose the most suitable one based on their own knowledge or by searching for relevant information to evaluate the answer eventually. As example, Table 19 demonstrates the question set for the sub criterion possible applications. Each set is structured the same way:

a) The headline shows always the name of the sub criterion
b) After the headline, a short description to the overall aim of the criterion is given
c) Then the questions, which have to be answered, are listed

Each question provides an additional description about the objective of the question, to make it more clear for the user and hence to give a more suitable answer. The answer options are built on the Likert scale, which is defined with constant intervals between choice options and allows to select a neutral answer as well[199]. Based on the question, the answer options are either

- Strongly agree, agree, neutral, disagree, strongly disagree

or

- Fully applies, largely applies, partially applies, does rather not apply, does not apply at all.

After one choice option is selected, the user has also to state, based on what information the question is answered. Again, choice options are available for the valuation.

Therefore, the following options are defined:

- Based on facts
- Based on partly facts/partly estimation
- Based on estimation

[199] Cf. Mayntz et al. (1978), p.55-58

The reason to define “based on” choice options is that they are used to calculate the unsureness of answered questions afterwards and hence provide an additional criterion to determine the overall attractiveness of a technology. Chapter 4.2.5 is dealing with the evaluation of the unsureness of answered questions more in detail.

Each question offers also a blank space for the possibility to write down notes why a certain choice option is taken. Notes can include a further insight to the evaluators thoughts, but can also contain statistics or calculations, which are necessary to answer the question.

After all sets of questions for every sub criterion are answered, the user gets the analysis in form of a portfolio visualization and as a score result for the overall technology and market attractiveness as well as the sub results for each sub criterion. To get a better understanding and overview of how an output of the answered questions looks like, a look ahead to Figure 34 in chapter 4.2.5 is helpful as it shows such a visualization sample. However, these outputs are discussed more in detail in the respective chapter.

It is important to note that the visible points next to the choice option (see Table 19) are not relevant for the user, but are necessary for the ongoing evaluation in chapter 4.2.5. One should be careful, since depending on the objective of each question, the points vary among different questions. Thus, the choice options “fully applies” or “strongly agree” imply not always the highest points. Also, the shown question weighting percentage is only needed in chapter 4.2.5 and is defined by the developer. Again, the question weighting is not relevant for the user and of course not visible during the evaluation process.

All question sets for each TAT sub criterion are found in Appendix C. These questions are derived by the recommended evaluation criteria and thoughts by Schimpf, Metze, Schimpf/Rummel, Mankins, Haag and Henriksen[200].

The question sets for the MAT sub criteria are listed in Appendix D. These questions are derived by the recommended evaluation criteria and thoughts by Bruhn, Schimpf, Mankins, Schimpf/Rummel, Metze and Henriksen[201].

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[200] Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.330-337; Cf. Henriksen (1997), p.615-633

[201] Cf. Bruhn (2001), p.56-74; Cf. Schimpf (2010), p.224-228; Cf. Mankins (2009a), p.1208-1215; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Metze (2008), p.325-346; Cf. Henriksen (1997), p.615-633

Table 19: Extract of question set for sub criterion possible applications[202]

POSSIBLE APPLICATIONS
The aim of this criterion is to identify if there are multiple options for the usage of the technology. Many possible applications for the technology in potential products increases the attractiveness of the technology and less possible usages decreases the attractiveness, respectively.
QUESTIONS
1) The technology is very specific and supposed to be for one to two products To identify the application breadth of the technology ***Evaluation options:*** Strongly agree (1), agree (2), neutral (3), disagree (4), strongly disagree (5) ***Question weighting (QW):*** 30%
2) Trends for beneficiary influence of the technology can be identified To identify possible trends and indicators for the evaluated technology which could justify the use of the technology ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 25%
3) Relevant branches with the need of a beneficiary technology can be identified To identify branches which already are and branches which could be interested in the future in using the technology ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 35%
4) Possible product categories which can use the new technology can be identified To identify potential product categories or products which could use the technology in the future ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 10%

[202] Own presentation; Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.330-337; Cf. Henriksen (1997), p.615-633

4.2.5 Evaluation of Technology and Market Attractiveness and Unsureness

This chapter discusses the procedure to determine the overall technology and market attractiveness as well as the unsureness of each question evaluation. The visualization of the assessment result is explained in the following chapter.

In the previous chapter, choice options for each question within a question set for evaluating their accuracy based on the Likert[203] scale have been debated. Now, the possible achievable score for each question is described more in detail.

Depending on the selected answer by the user, the score varies between 5 (highest achievable score, HAS) and 1 (lowest achievable score, LAS). The higher the score for TAT and MAT in the end is, the more attractive the technology is. It must be mentioned again that the choice options “fully applies” or “strongly agree” bring not always the highest score, since it depends on the question’s aim. However, after the user selects a choice option, the evaluation score is always calculated automatically by the Excel program and visible but not of concern for the user.

Next, the choice options to select on what information the answer is responded, implies a weighting for the ongoing unsureness determination. More details to this issue are following within this chapter.

Figure 32 shows an example of a typical structure of randomly filled out question sets. Thus, the following four steps for the evaluation of one question has to be followed by the user:

1. Read the defined question carefully
2. State in the justification column, where relevant information to the answer can be found (e.g. statistics or reports)
3. Answer the question by choosing one of the five choice options in the evaluation column (e.g. partially applies or does rather not apply)

Then the corresponding score to the answer of the user is calculated automatically by the Excel program. The achieved score is set visible for the user in the score column and also a horizontal bar visualizes the achieved points out of the possible maximum.

Now, the user has to continue the question evaluation with the last step:

4. Choose an option on what information the answer is responded in the based on column (e.g. based on facts or based on estimation).

[203] Cf. Mayntz et al. (1978), p.55-58

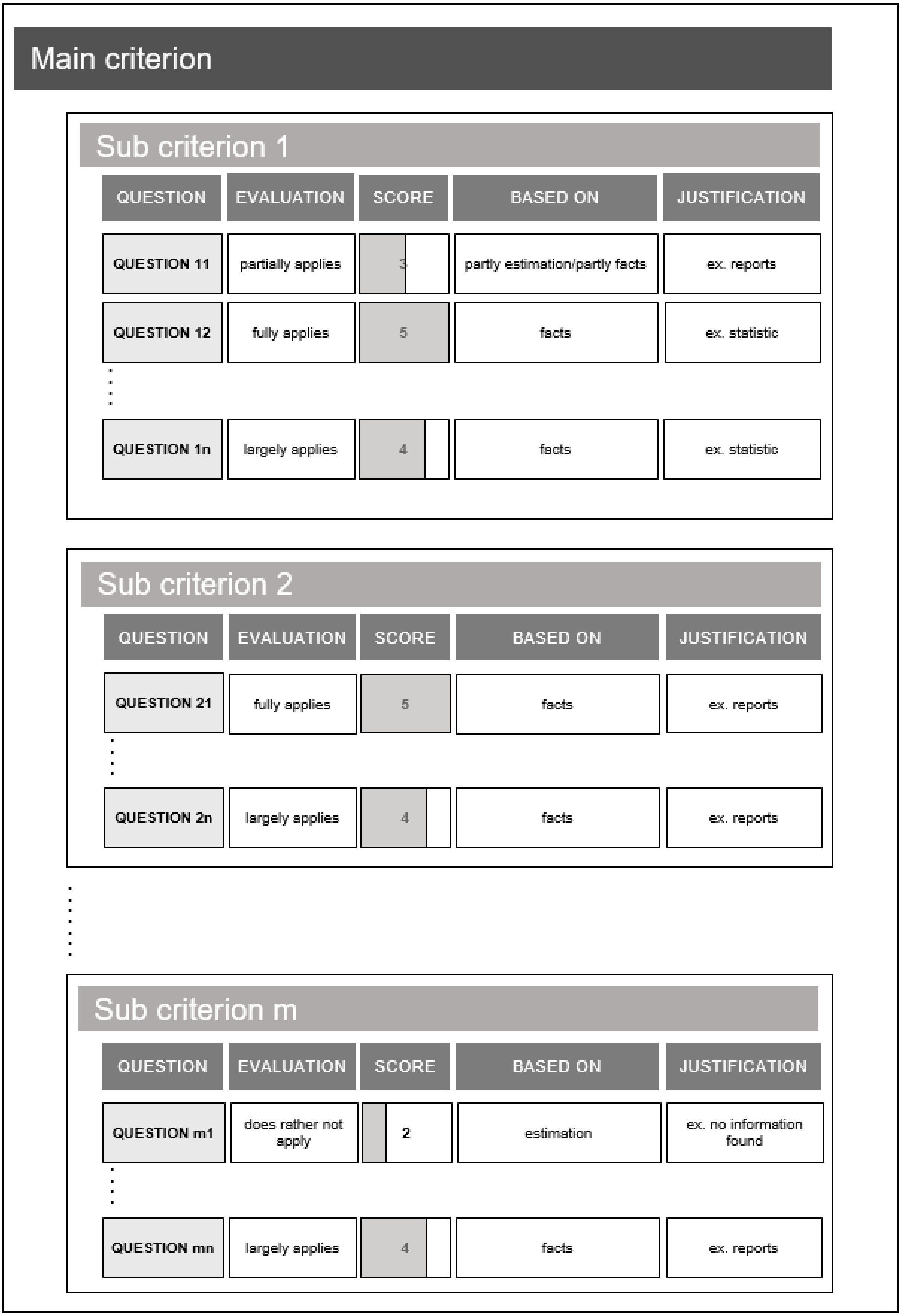

Figure 32: Concept of question evaluation[204]

To demonstrate the calculation process of a main criterion (e.g. TAT and MAT), the structure of Figure 32 is used. Each of the randomly filled out question sets belong to a sub criterion k, whereby k describes the respective sub criterion and serves also as control variable for the calculation. The main criterion is built on sub criteria $k=1$ to $k=m$, whereby the index m describes the number of sub criteria. Within each sub criterion k, l questions are provided, whereby l describes the respective question within a question set and serves as control variable too. Again, the question set is structured in several question $l=1$ to $l=n$, whereby the index n describes the number of questions within a question set.

For the calculation process of each question l within a set to a corresponding sub criterion k, the following list of parameters derived from Figure 32 are defined:

Parameters for the ongoing calculation:

CW_k	Criterion weighting from pairwise comparison
ES_{kl}	Evaluation score from the user
QW_{kl}	Question weighting defined by developer
$UAQF_{kl}$	Unsureness of answered question factor

As seen in Figure 33, the determination of the attractiveness of the main criterion (e.g. TAT and MAT) is explained. With the use of equation (3), the overall result for the main criterion is calculated.

$$result\ attractiveness\ main\ criterion = \sum_{k=1}^{m} \{CW_k \times [\sum_{l=1}^{n} (QW_{kl} \times ES_{kl})]\} \qquad (3)$$

Figure 34 shows a sample output for the user by listing all sub results to each sub criterion k as well as the overall result for the main criterion TAT and MAT, respectively. The horizontal bar is used to visualize the achieved percentage out of the achievable maximum for each criterion k. The highest possible sub result for a sub criterion k is calculated by equation (4).

$$maximal\ sub\ result\ criterion\ k = CW_k \times HAS \qquad (4)$$

Due to the highest score which can be achieved for a question l within a sub criterion k is 5 points, through the criterion weighting and question weighting, the maximum TAT score which can be reached is also 5 points. Similarly, the maximum MAT score which can be reached is 5 points.

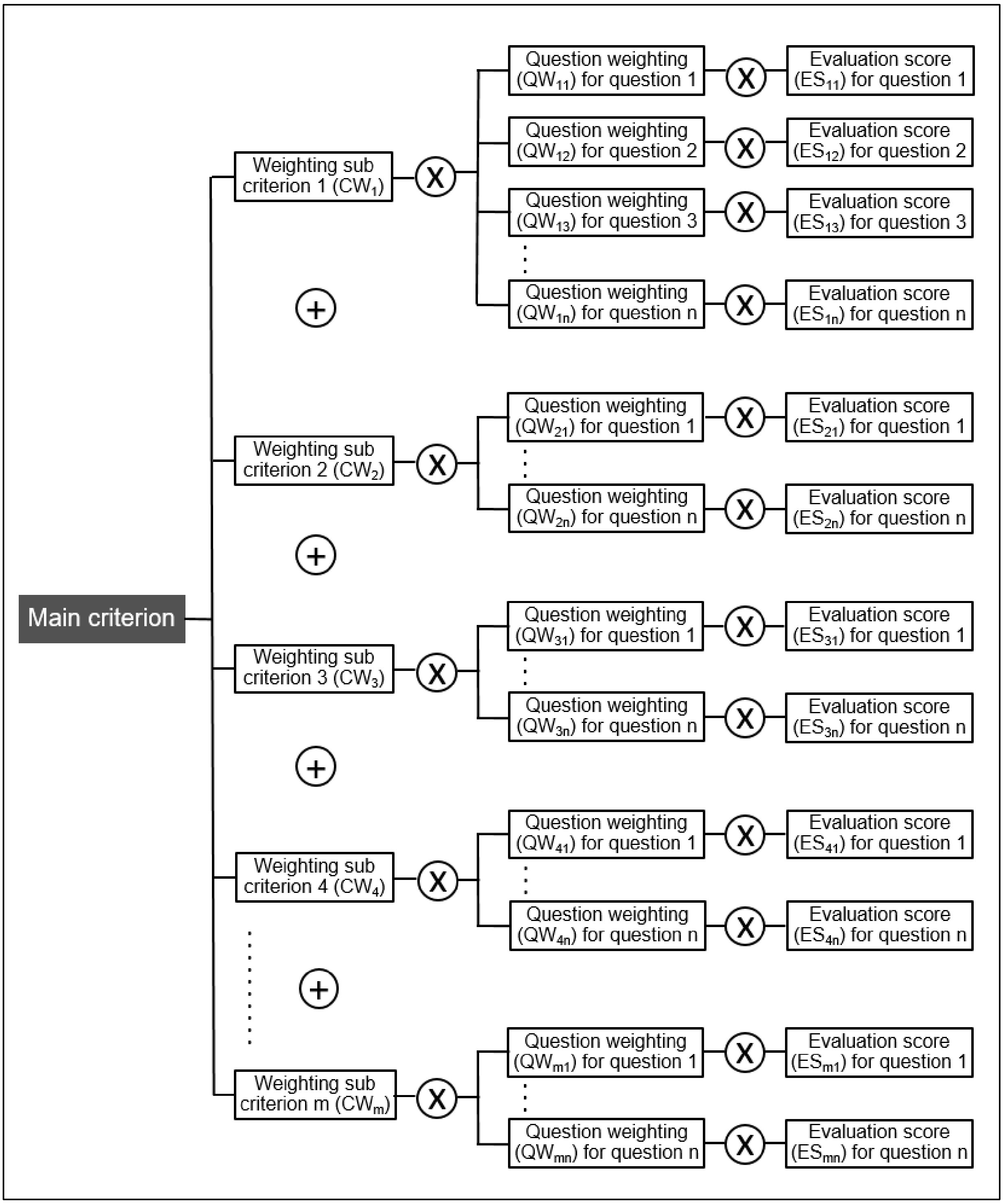

Figure 33: Calculation of the main criterion[205]

[205] Own presentation

Unsureness of answered questions

As already mentioned in chapter 4.2.4, the reason to define “based on” choice options is that they are used to determine the unsureness of the filled out questions and hence provide additional information to the attractiveness of a technology. Therefore, an unsureness of answered question factor (UAQF) is defined and its definition is listed in Table 20.

Table 20: Definition of question unsureness percentage

UAQF	DEFINITION
100%	A percentage of 100% unsureness is given for the option based on estimation
50%	A percentage of 50% unsureness is given for the option based on partly facts and partly estimation
0%	A percentage of 0% unsureness is given for the option based on facts

The unsureness of the filled out questions of the main criterion is determined similarly to the determination of the attractiveness of the main criterion (see equation (3) and Figure 33). With the use of equation (5), the unsureness of the answered questions (UAQ) of the main criterion is determined. The only difference is the change of the evaluation parameter ES_{kl} to the unsureness of answered question parameter $UAQF_{kl}$, which is indirectly chosen through the user during the evaluation of the questions by choosing one of the “based on” choice options (see chapter 4.2.4). Again, the index k describes the respective sub criterion and the index l the question within the question set of the sub criterion k. The index m defines the number of sub criteria and the index n the number of questions within it.

$$unsureness\ of\ answered\ questions\ [\%] = \sum_{k=1}^{m}\{CW_k \times [\sum_{l=1}^{n}(QW_{kl} \times UAQF_{kl})]\} \times 100 \quad (5)$$

This equation (5) is valid for the determination of the UAQ for the TAT as well as for the MAT. Figure 34 illustrates a sample visualization of the question unsureness percentages of the TAT and MAT. Moreover, a look ahead to Figure 35 is helpful as it demonstrates the assessment results of eight technologies placed within a portfolio with the determined vertical and horizontal UAQ for TAT and MAT.

TECHNOLOGY ATTRACTIVENESS		
CRITERIA	RESULT	ACHIEVED PERCENTAGE OF MAXIUM
RESULT POSSIBLE APPLICATIONS	1,24	93%
RESULT TECHNOLOGY MATURITY	0,69	59%
RESULT POTENTIAL OF DEVELOPMENT	0,47	56%
RESULT ALTERNATIVE TECHNOLOGIES	0,83	71%
RESULT DYNAMIC OF TECHNOLOGY	0,30	60%
UNSURENESS OF ANSWERED QUESTIONS TAT		13,0%
RESULT TECHNOLOGY ATTRACTIVENESS	3,52	

MARKET ATTRACTIVENESS		
CRITERIA	RESULT	ACHIEVED PERCENTAGE OF MAXIUM
RESULT MARKET TREND	0,70	60%
RESULT MARKET VOLUME	0,83	100%
RESULT MARKET QUALITY	0,74	74%
RESULT MARKET ACCESS	0,65	56%
RESULT MARKET ENVIRONMENT	0,58	70%
UNSURENESS OF ANSWERED QUESTIONS TAT		21,0%
RESULT MARKET ATTRACTIVENESS	3,51	

Figure 34: Sample output of evaluation results[206]

[206] Own presentation

4.2.6 Portfolio Visualization of Technologies

As already mentioned in the beginning of chapter 4.2, step 2 of the developed assessment approach is dealing with technologies gained from the pre-filtering process of step 1. Since step 2 is called portfolio pre-assessment, the form of visualization used for the calculated assessment results of chapter 4.2.5 is a portfolio. Now, the purpose of this chapter is to debate the structure of the portfolio and the actions which can be derived through its usage.

As shown in Figure 35, the portfolio is structured in 3 criteria:

- Technology attractiveness
- Market attractiveness
- Unsureness of answered questions for TAT and MAT

The ordinate of the portfolio illustrates the technology attractiveness and the abscissa describes the market attractiveness. A technology can achieve a HAS of 5 and a LAS of 1 for each of these two criteria. The unsureness of answered questions for TAT and MAT is represented through a grid within the portfolio. Therefore, a vertical (for TAT) and a horizontal (for MAT) deviation line shows the respective unsureness to each technology's assessment result. The longer the vertical and horizontal deviation lines for a technology are, the higher the respective UAQ is. To visualize the UAQ, the assumption is made that the overall assessment result of the evaluation is the center of the unsureness. Moreover, it is assumed that the UAQ deviation percentages are the same in each direction. The procedure for every technology for portfolio visualization is as follow:

1. Evaluate the TAT by the defined criteria
2. Evaluate the MAT by the defined criteria
3. Calculate the UAQ for TAT and MAT
4. Place the technology with its overall assessment result for TAT and MAT in the portfolio
5. Use the UAQ as third criterion within the portfolio to demonstrate the vertical and horizontal deviation

After each of the technologies are placed within the portfolio, the vertical and horizontal deviation line for each technology are calculated by Excel. Therefore, the user has to provide Excel with the respective UAQ percentages for TAT and MAT to each technology. As the HAS is defined by 5 and the LAS by 1, the subtraction of these two scores is 4 and represents the vertical as well as the horizontal portfolio score size. As a consequence, 100% unsureness of answered questions for a technology corresponds to a score of 4. This awareness uses Excel to calculate automatically the respective deviation lines within the portfolio chart for a technology's TAT and MAT.

Figure 35 shows a possible output of assessed technologies, which are demonstrated as dummy technologies in this case. As already mentioned, the longer the deviation lines, the higher the UAQ of a technology for the respective attractiveness is. Whereas for example "technology 1" has one of the shortest deviation lines, the deviation lines of "technology 2" are one of the longest ones. Hence, that implies that the question sets for "technology 1" are mainly answered by facts, and that the question sets for the "technologies 2" are mostly answered by estimations. Therefore, this criterion provides the user with additional important information regarding the reliability of the assessment result.

The values for the unsureness of answered questions for TAT and MAT to a technology are provided with the aid of a grid within the portfolio (see Figure 35). As a consequence, each UAQ cell of the grid describes vertical as well as horizontal an UAQ percentage of 5%. Therefore, to get the respective UAQ percentages for TAT and MAT to a technology, the user has to sum up the corresponding UAQ cells from the center of a technology to the end of the deviation line. For example, the UAQ percentage of MAT for "technology 7" is calculated by summing up the UAQ cells from the center of the technology to the negative end of the deviation line and is 20% ($4x5\%$). As the assumption is made that the overall assessment result of the technology is always in the center of the unsureness, the deviation lines have the same length in positive and negative direction. Therefore, the same unsureness result for "technology 7" for MAT is achieved by summing up the UAQ cells from the center of the technology to the positive end of the deviation line and is again 20%.

As seen in Figure 35, it looks like that some of the UAQ deviation lines exit the portfolio (e.g. "technologies 4, 5, 7 and 8"). Since the portfolio is limited with the HAS of 5 and the LAS of 1, the maximum achievable score for a technology's TAT and MAT is also limited by these boundaries and hence, although the UAQ deviation lines seems to be exiting the portfolio, the scores cannot be outside of the valid portfolio area.

The aim of this portfolio analysis is to detect technologies, which have due to the portfolio assessment the highest potential for being successful in the future. These technologies are then used to conduct a detailed technology assessment separately for each technology in step 3. As obvious in Figure 35, the technology "4" has one of the highest TAT scores, but a low MAT score. Conversely, "technology 8" has a high MAT, but a low TAT. Thus, these technologies are not the best choices for conducting a detail technology assessment. Although the technologies "1,5 and 7" have not the highest scores for TAT and MAT, these technologies provide the best mixture of a relative high TAT and MAT as well as a relative low UAQ percentage. Therefore, these technologies can be chosen for a detailed technology assessment within step 3.

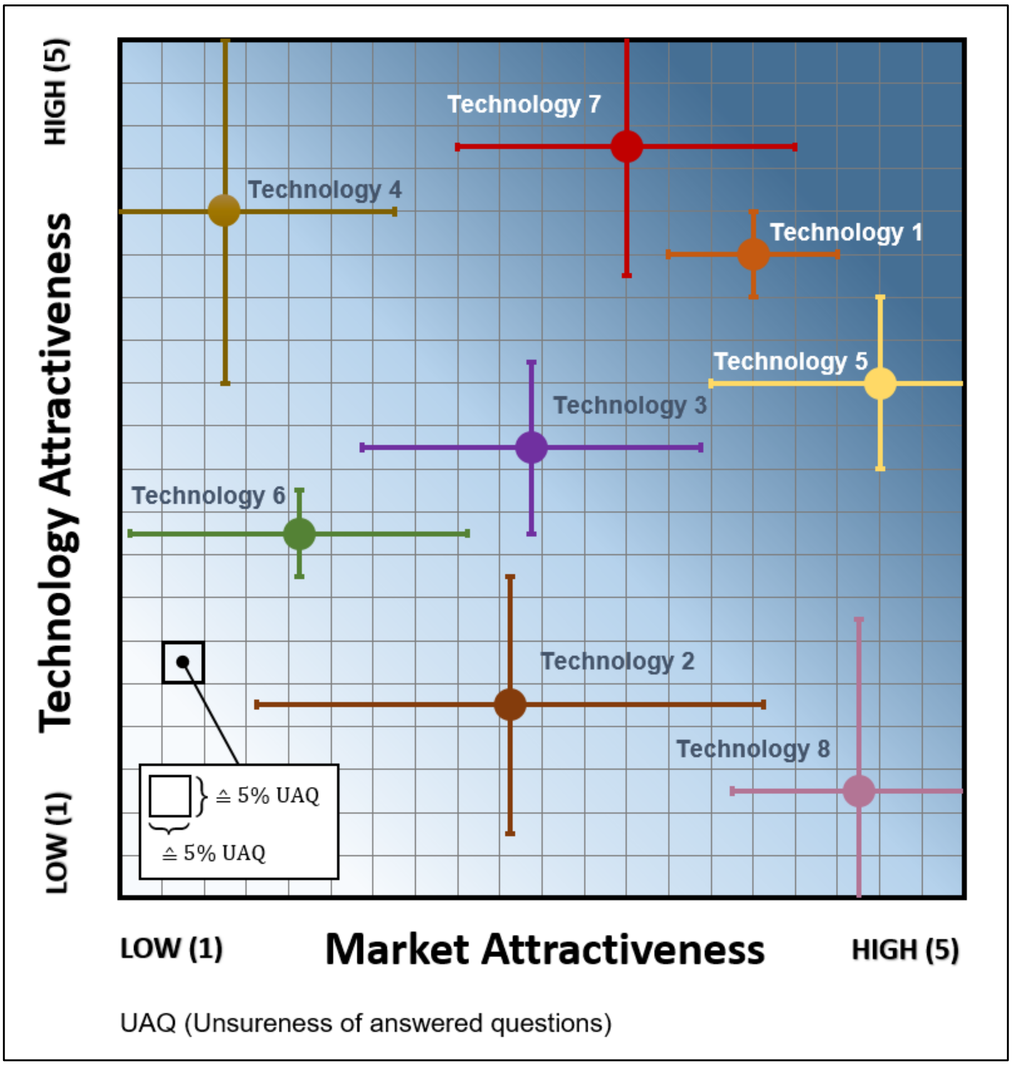

Figure 35: Visualization of technology evaluation[207]

[207] Own presentation

4.2.7 Verification and Development of Portfolio Concept

This chapter is dealing with the verification and development of the portfolio concept. The aim of the verification is to analyze, if different users of the portfolio would come to the same assessment result for a technology, if they have the same information as input. Therefore, a verification process is conducted by four participants, who get the same case study for evaluating a technology and their results are compared afterwards.

For the verification of the portfolio, the technology lithium-ion is used. As everyone knows nowadays about the importance of lithium-ion accumulators in daily life, this technology was widely unknown in the year 1993. Therefore, no one could predict the technology's importance to human in 1993 and that is exactly the issue where the case study starts. The out handed case study to the participants is dealing about an investment decision in lithium-ion accumulators out of the view of the notebook enterprise Dell. All opportunities, threats and performance facts to the technology are stated within the case study. The output of the evaluation is supposed to deliver a result, if the technology is worth an investment for the future.[208]

Table 21 lists and Figure 36 visualizes the verification results of all four participants regarding the technology's TAT and MAT. With the exception of person 2, all other three participants achieved an almost identical result for the TAT and MAT. After a thorough analysis of the evaluation results of participant 2, parts of the deviation can be led back to a misinterpreting of the proposed questions and hence an inexact evaluation of the question sets. The reason for this conclusion is that some facts are precisely stated in the case study, but not appropriately answered by the participant.

Table 21: Verification results of lithium-ion technology[209]

Criteria \ Participants	Person 1	Person 2	Person 3	Person 4
TAT	3,72	3,37	3,85	3,96
MAT	3,91	3,45	4,13	4,05

[208] Cf. Thomke at al. (1998), p.1-21
[209] Own presentation and calculation

Although the assessment results of the participants are rather similar, the following improvements to the portfolio analysis have been made:

- Some questions are defined more precisely to avoid misinterpreting
- An additional description to the objective of every question is given
- An explanation to each sub criterion’s aim is given before the user starts with the evaluation of the corresponding question set. Thus, the user gets already in the beginning an insight of the purpose of each sub criterion and is more aware of giving an appropriate evaluation.
- A third criterion is defined, which evaluates the unsureness of the answered questions for TAT and MAT and hence gives additional information of the accuracy of the assessment result

In summary it can be stated that the portfolio development was worth the effort. The portfolio provides all the necessary assessment information, which are expected. Therefore, it allows one to choose the best evaluated technology from the portfolio and to conduct a detailed technology assessment in the ongoing step 3.

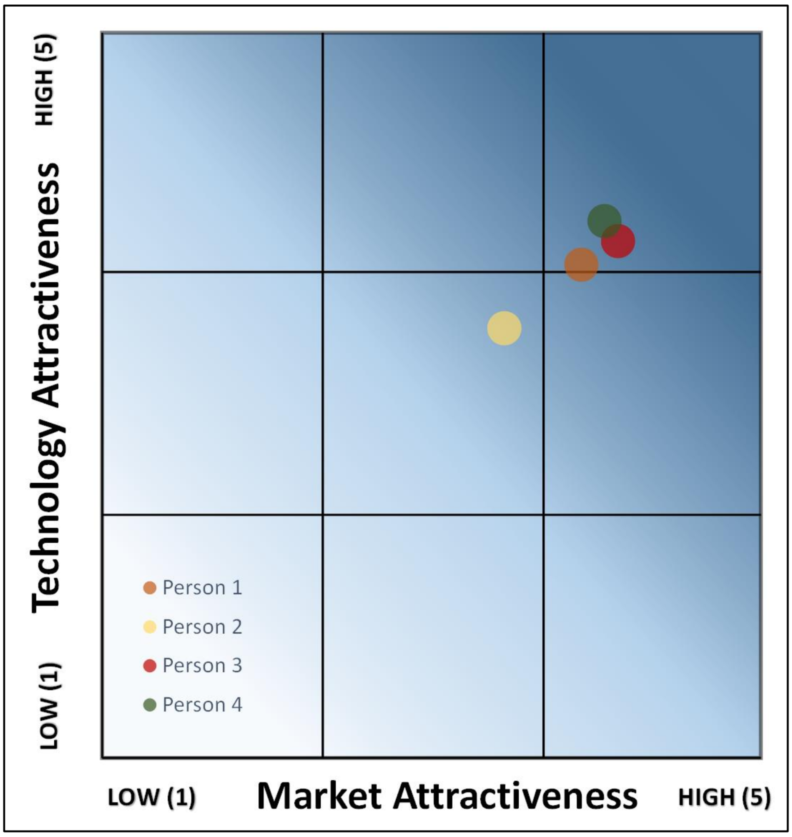

Figure 36: Visualization of portfolio verification[210]

[210] Own presentation and calculation

4.3 Detailed Technology Assessment

The last step within the 3-step approach is the detailed technology assessment process. Its overall aim is to provide the investor with technologies, which have, compared to the other technologies of the technology catalog, the highest potential for being successful in the future and hence are worth an investment. This step is conducted for each chosen technology separately.

Again, necessary requirements for the development of this step are stated. The following requirements are identified:

- The analysis should be more thorough compared to the previous 2 steps
- The approach should list competitors (technology owner), who deal with the technology or a similar one
- The approach should allow one to compare competitors among each other
- The evaluation results should be transparent and comprehensible
- The evaluation process should not be technology field specific

Also, further objectives for the detailed technology assessment process, besides providing the investor with a technology for a potential investment, are defined:

- Deliver a competitor, who applies the technology, and where a potential investment is feasible and rational
- Visualize the assessment results for a clearer understanding
- Provide information sources, where data of competitors can be found

Input for the detailed technology assessment process

As input for the detailed technology assessment serves one of the identified technologies from the portfolio analysis, which has due to the evaluation process in chapter 4.2 a relative high combination of a TAT and MAT score as well as a low unsureness of answered questions. However, if the chosen technologies from the portfolio analysis do not lead to an investment opportunity, additional technologies from the portfolio can be chosen as other inputs for the detailed technology assessment.

Output of the detailed technology assessment process

The output of the detailed technology assessment process is supposed to provide the investor a competitor, who deals with the identified technology, and where an investment in this company or startup is promising for the future. Depending on how many from the step 2 identified technologies are still worth an investment after the detailed technology assessment, the investor can also invest in a various of different technologies.

The following sub chapters discuss the defined criteria of the competitor evaluation as well as how the assessment process is conducted. Moreover, web pages and data bases for gathering relevant evaluation information are introduced. In addition, a visualization in form of a table including all competitor assessment results is shown.

Also in this step, Microsoft Excel is used as software. The Excel file contains all relevant evaluation results and provide the visualization table.

4.3.1 Use of Startup Scorecard to define Assessment Criteria

This chapter debates the startup score card, which is an assessment tool for startups and allows an investor to evaluate competitors by grades and to compare competitors among each other afterwards[211]. In chapter 4.3.3, the evaluation procedure is shown more in detail with the aid of an appropriate example.

The startup score card is based on the six market dynamics, which are illustrated in Figure 37. All of these six market dynamics are necessary and have to be evaluated to gain a better understanding of threats and opportunities a startup can imply. Thus, the startup founder gets more aware of the market situation and hence can derive a better strategy.[212]

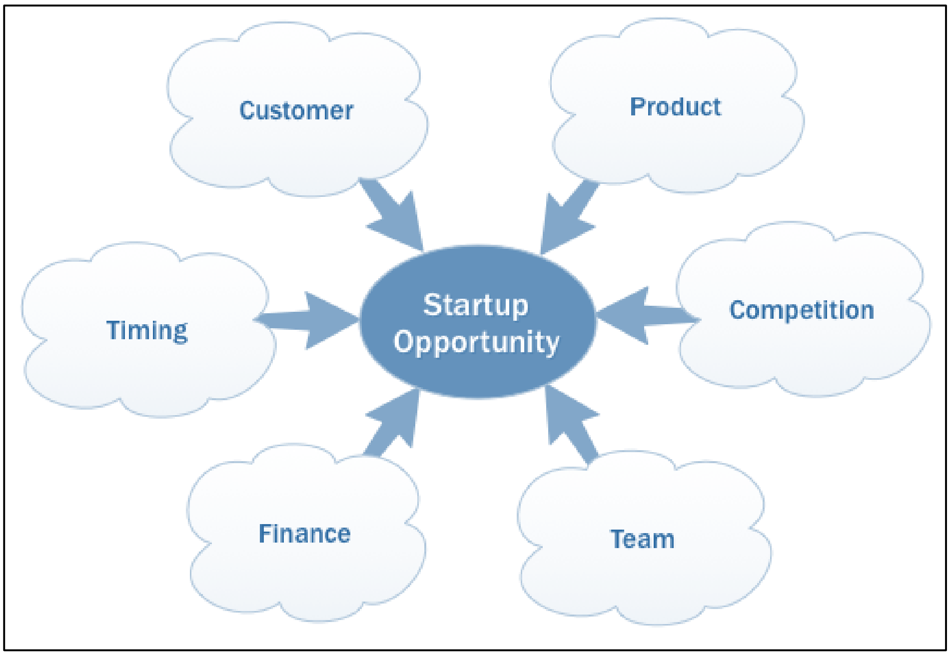

Figure 37: The 6 market dynamics[213]

[211] Cf. www.smarterstartup.org (04.11.2016)
[212] Cf. www.smarterstartup.org (04.11.2016); Cf. www.smarterstartup.org (31.01.2017)
[213] Cf. www.smarterstartup.org (31.01.2017)

The six market dynamics are defined as follow:[214]

- **Customer**
  "Who are you going to serve and what need or desire do you plan to address?"

- **Product**
  "What is the solution to the customer's need or desire and is it in a form that the customer will embrace?"

- **Timing**
  "Is market timing favorable or are you going to be fighting an uphill battle?"

- **Competition**
  "How strong is the competition and how open is the market to a new entrant?"

- **Finance**
  "How much capital must you invest and do the returns justify the risk?"

- **Team**
  "How fit is your team to be a leader in providing the proposed solution?"

These six market dynamics are the basis of the startup scorecard and have to be evaluated by the investor to get an overview of the opportunities a startup has. Figure 38 represents the startup score card for these 6 topics, but with an extension by adding the development stage to the score card[215].

The evaluation of each topic is then conducted by giving grades for each topic and an overall assessment grade for a competitor is calculated by building the average grade including all seven topic grades. Therefore, the main issues for evaluating each topic are listed within each topic in Figure 38 and additional facts to the issues are given during the ongoing chapter.[216] Further details to the evaluation process are discussed in chapter 4.3.3 and the visualization of its results described with the aid of a competitor table.

[214] www.smarterstartup.org (31.01.2017)
[215] Cf. www.smarterstartup.org (04.11.2016); Cf. Mankins (1995), p.1; Cf. Mankins (2009a), p.1211
[216] ibidem

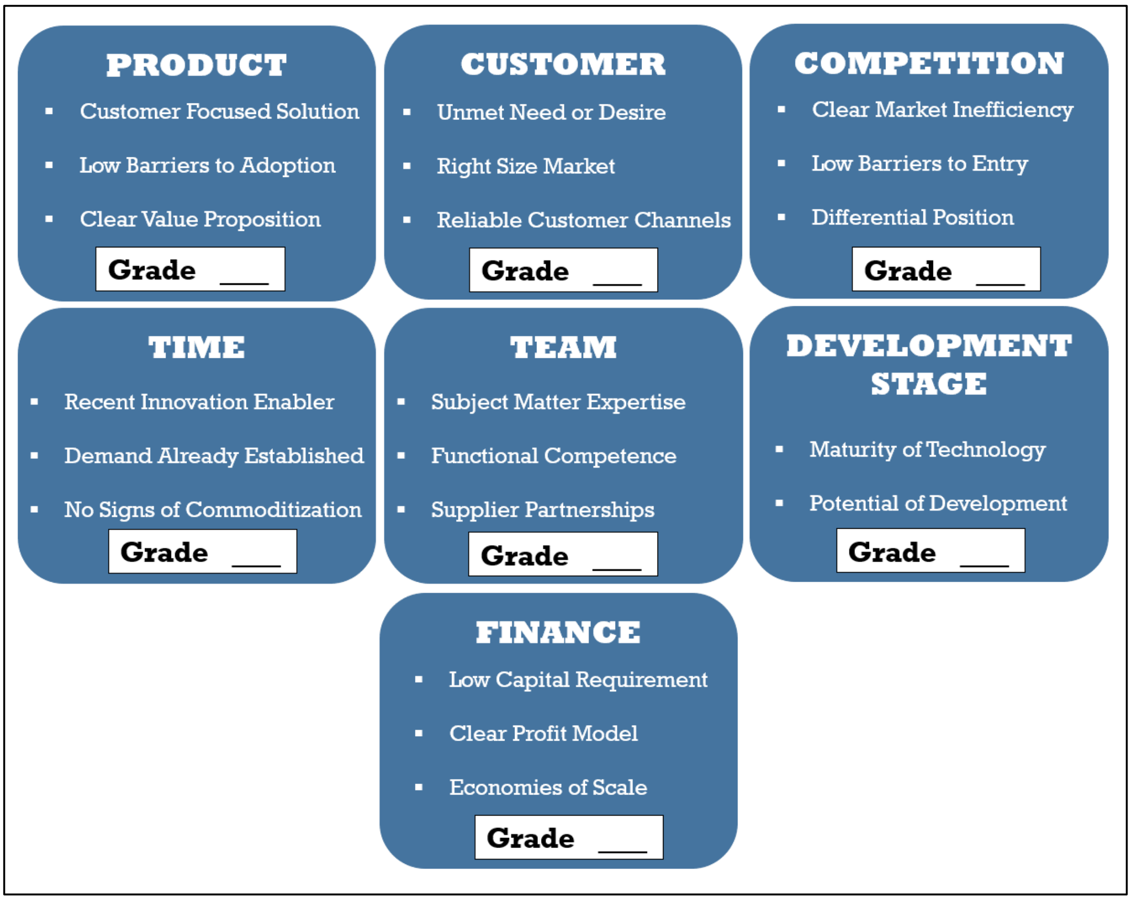

Figure 38: Extended startup scorecard[217]

Product

A good product will always sell itself. Thus, it is necessary to develop a product, which fulfill the customer needs and desires and which is easy to understand and manageable. Moreover, one has to avoid barriers which lead that customers are not going to adopt the product. Also, one has to make the benefit of the product obvious for the customers that no one has to be convinced of its reasonableness.[218]

Customer

The ideal customer is searching for a product to fulfill an unmet need or desire of the customer, which is not solved yet. Therefore, one has to be aware to size the right market, which can be serviced with the own abilities. Furthermore, a reliable access to the customers is indispensable for the business's success.[219]

[217] Cf.www.smarterstartup.org (04.11.2016); Cf. Mankins (1995), p.1; Cf. Mankins (2009a), p.1211
[218] Cf.www.smarterstartup.org (04.11.2016)
[219] ibidem

Competition

Place a product in those markets, where still an inefficiency exists and where one can gain competitive advantage by developing an appropriate product. In addition, avoid entering markets with high barriers and markets where a competitor has already a high market share. Moreover, the product can be similar to other products, but it has to have a competitive advantage against the others and hence cannot be replaced by others.[220]

Time

The more mature the market is, the less attractive it gets for startups since it has to fight to get an appropriate market share. Therefore, the objective of each startup has to be, to be a “fast follower” in an emergent market, where the demand was already established by someone else.[221]

Team

To have success with a product on the market, a team with deep knowledge in the fields of market analyses and technical competences are necessary to address the markets needs and desires. Also, supply partnerships are essential to the startup’s success and hence have to be chosen well.[222]

Development stage

Within this step, the maturity of the technology according to the TRL in chapter 3.5.2 is assessed. The more mature the technology is, the lower the investment risk. Moreover, the potential of development is analyzed.[223]

Finance

Costs for the development of a product should always be kept to a minimum, especially when the product’s demand is not clearly identified yet. Economies of scale help to reach higher margins. Avoid that the capital is locked up and define a clear profit model.[224] The higher the previous investment in a technology has been, the more unattractive it gets for a potential investor.

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[220] Cf.www.smarterstartup.org (04.11.2016)
[221] ibidem
[222] ibidem
[223] Cf. Mankins (1995), p.1; Cf. Mankins (2009a), p.1211
[224] Cf.www.smarterstartup.org (04.11.2016)

4.3.2 Gathering Information of Competitors

This chapter contains a list of potential information sources, which can be used to gather all relevant information to evaluate the defined criteria of the previous chapter. The following six data sources are introduced briefly:

- Austrian Angel and Investor Association
- Oddupp Startup Rating System
- Crunchbase
- Trendkite
- Serious Funding
- AngelList

Austrian Angel and Investor Association

The Austrian Angel and Investor Association links dedicated and talented entrepreneurs to experienced business angels, who are interested in a communication of mutual experiences, know-how, networking and the realization of new and innovative ideas as well as exciting and revolutionary business models. Through being a member of this association, an update of angel investments and a list of opportunities for co-investments are provided continuously.[225]

Oddupp Startup Rating System

Oddupp is a platform, where startups are rated based on research data and hence provides the user with analytical information. Thus, Oddupp is evaluating each startup for their probability of being successful in the future. The data Oddupp uses varies from the product itself, the startup's growth and potential investors. At the moment, only startups located in Asia are part of the Oddupp rating, but an extension to Europe is held out in prospect.[226]

Crunchbase

Crunchbase is a business information platform. Their aim is to identify industry trends and to provide them on their platform in form of analyzes afterwards. Moreover, Crunchbase discovers news of companies, lists done investments or provide information

[225] Cf. www.aaia.at (14.11.2016)
[226] Cf. www.oddup.com (14.11.2016)

of the firm's team and competencies. Compared to Oddupp, Crunchbase provide information of companies worldwide.[227]

Trendkite

The company Trendkite measures the impact of press releases (PR) of enterprises and reports is afterwards. Therefore, the firm provides a product for PR impact measurement, a product for PR monitoring and a product for transforming the analyzed data into a report, which includes statistics and gives the opportunity to derive trends and hence to develop an investment strategy.[228]

Serious Funding

The actual aim of the company Serious Funding is to get funding for startups in a serious and fast way. However, the firm evaluates startups by analyzing the idea, the team, the startup itself, the market and the finance parameters. The enterprise applies the scorecard method, the checklist method and the venture capital method for the valuation of the startup.[229]

AngelList

The firm AngelList is already introduced in detail within the pre-filtering process in chapter 4.1.2. Summarizing, the company provides similar to Crunchbase information of previous investments, the team, the followers and the product. Moreover, it is a platform for raising money and to recruit employees.[230]

All introduced companies represent a possibility for applying those to collect the relevant information to evaluate the defined criteria of the extended startup scorecard of Figure 38. If the relevant information to the competitor cannot be found, then the investor has to get in contact directly with the competitor and request the necessary information for conducting the evaluation. Also, experts can be helpful within this step to provide informative data. Moreover, experts can also serve as support for making an investment decision eventually.

[227] Cf. www.crunchbase.com (14.11.2016)
[228] Cf. www.trendkite.com (15.11.2016)
[229] Cf. www.seriousfunding.be (15.11.2016)
[230] Cf. www.angel.co (04.09.2016)

4.3.3 Evaluation of Competitors

The objective of this chapter is to demonstrate the evaluation procedure of the defined criteria in chapter 4.3.1. Therefore, the topics of

- Product
- Customer
- Competition
- Finance
- Time
- Team
- Development stage

are evaluated by the investor by ascribing each topic a grade. The overall assessment grade of the competitor is then calculated by building the average with the seven sub grades.

The grades are defined by the Austrian grading scale. Table 22 lists and gives also a short description to each grade.

Table 22: Grading system for competitor assessment

GRADE	DESCRIPTION
1	Excellent; outstanding performance of the competitor
2	Good; performance is about the average, but there are still better ones
3	Satisfactory; average performance of competitor
4	Sufficient; performance meets the minimum of the defined criteria
5	Unsatisfactory; performance is not acceptable

Figure 39 illustrates an example of a typical structure of a randomly filled out competitor evaluation. Due to the limited horizontal space of the page, only three criteria are listed in the picture for showing the evaluation procedure. The following steps have to be conducted to evaluate each competitor:

1. Choose the first criterion out of the seven topics
2. Search for the relevant information to evaluate this criterion based on the main issues described in chapter 4.3.1 and by applying the introduced sources in chapter 4.3.2
3. State the found main relevant data to the corresponding competitor within the proposed cell

4. Compare for one criterion the gathered data of all competitors to detect differences between them
5. Assign a grade to each competitor based on the comparison valuation of step 4
6. Choose another criterion and conduct the steps 2-5 again, until every criterion for each competitor is evaluated by ascribing grades
7. Built the average grade of each competitor by their seven sub grades to identify the best evaluated one

COMPETITOR	PRODUCT	GRADE	CUSTOMER	GRADE		FINANCE	GRADE
COMPETITOR 1	Product 1	2	Customer 1	1		Investment 1	5
COMPETITOR 2	Product 2	2	Customer 2	2		Investment 2	3
COMPETITOR 3	Product 3	3	Customer 3	3		Investment 3	3
COMPETITOR 4	Product 4	2	Customer 4	2	......	Investment 4	4

Figure 39: Extract of concept of competitor evaluation[231]

As the more competitors have to be evaluated and the more facts to each competitor are gathered, the more complex the table within the Excel file gets. As a consequence, the investor is losing the overview of the interesting and uninteresting competitors immediately and hence loses the opportunity to detect these competitors, where an investment is promising. To solve this problem, a competitor table is designed, which collects only the sub grades and the average grades of a competitor and visualize them in a more structured way. The competitor table and the implied benefits of using it are explained more in detail in the next chapter.

[231] Own presentation and evaluation

4.3.4 Competitor Table

As already introduced in the previous chapter, the competitor table allows the investor to visualize all sub grades and the average grade of each competitor within one table. Side information of how grades are achieved, are not apparent of the table.

Figure 40 illustrates an example of how a competitor table look like. The competitors are listed on the vertical axis and the seven criteria are shown on the horizontal axis. The core of the table represents the main information about the grades of a competitor to every criterion. Moreover, the last column reveals the average evaluation of each competitor and the last row the average evaluation of each criterion.

COMPETITORS	Product Score	Customer Score	Competition Score	Finance Score	Timing Score	Team Competence Score	Development Score	AVERAGE COMPETITOR
Competitor 1	2	1	2	5	1	1	1	1,9
Competitor 2	2	2	3	3	2	2	1	2,1
Competitor 3	3	3	3	3	2	2	1	2,4
Competitor 4	2	2	3	4	2	2	1	2,3
Competitor 5	2	4	2	3	1	2	2	2,3
Competitor 6	1	3	1	1	2	3	4	2,1
Competitor 7	4	3	3	5	2	1	2	2,9
Competitor 8	3	3	3	2	2	3	3	2,7
Competitor 9	3	3	3	1	2	4	4	2,9
Competitor 10	4	3	3	5	1	1	2	2,7
AVERAGE CATEGORY	2,6	2,7	2,6	3,2	1,7	2,1	2,1	

Figure 40: Competitor table[232]

[232] Own presentation

As one may have already noticed, Figure 40 visualizes grades red, which are worse than satisfactory (3). In addition, the Excel program highlights the three best evaluated competitors with the best average grade in green. It is important to note that not the best evaluated competitor for a potential investment should be chosen automatically, since one criterion can be just graded with sufficient (4) or worse. Therefore, the investor has to be always aware to have a more precisely look at the sub results of each criterion to get a more informative basis for a decision eventually.

As example, based on the sample evaluation of Figure 40, the best choice for an investment would be “competitor 1”, since it has the best average grade. However, “competitor 1” has been assigned a grade of unsatisfactory (5) in the criterion finance and hence an investment is not promising for the future. Comparatively, “competitor 2” could be worth an investment, as of the second best average grade and no assigned grades worse than satisfactory (3).

5 Conclusion and Outlook

The overall aim of each firm is to make profit and hence to keep their business alive. Through continuously strengthening the core competencies by applying new technologies to stay competitive on the global marketplace, this aim can be achieved. Thus, technology assessment methods and tools aid by identifying promising technologies for the future.

Within this thesis, a technology management process used in enterprises is explained in detail to show how technology assessment is part of it. Also, technology assessment methods are collected and structured in categories for different purposes. Methods are listed to analyze the technical performance, risks, the system, the market and externalities as well as impacts. Also, technological forecasting methods and economic analyses are part of the collection.

Based on the investigation of already existing technology assessment approaches for firms found in the literature, an assessment approach for investors is developed by diminishing disadvantages of the present ones and by tailoring the approach to the investors' needs. The developed assessment approach is structured in following steps:

1. Pre-filtering process
2. Portfolio pre-assessment
3. Detailed technology assessment

The aim of the approach is to detect technologies, which are worth an investment. Therefore, the number of potential contemplable technologies is reduced continuously step by step. In addition, the evaluation of technologies gets always more thorough step by step to find technologies, which have compared to the other technologies more potential for being successful in the future. To each step within the approach, appropriate assessment criteria are defined. Moreover, information sources to each step for getting the relevant data for evaluation are demonstrated. To make assessment results within each step clearer, visualization tools are applied.

In step 1 of the assessment approach, the focus lies on doing a quantitative evaluation, but allows the investor to include qualitative meanings such as of experts as well. Within this step, technologies can be sorted and filtered based on own preferences by using the assessment results or own experiences.

In step 2 of the assessment approach, a portfolio is derived based on the investigation of existing technology and market portfolios. The derived portfolio builds on the superior criteria market and technology attractiveness, but is evaluated by defined sub criteria, which are weighted through a pairwise comparison for their evaluation influence. To evaluate the respective attractiveness, a set of questions to every sub criterion is created and its evaluation procedure shown. Additionally, a list of useful assessment criteria for technology assessment is proposed. To verify the portfolio, participants are chosen to evaluate with the aid of a case study the same technology. Results showed that they achieved similar scores and that only small adjustments to the question sets and to the evaluation procedure had to be made.

In step 3 of the assessment approach, the remaining competitors are analyzed separately. Competitors which deal with the detected technology are listed and evaluated by ascribing them grades of defined assessment topics. The average grades of the competitors are shown in a competitor table, where one competitor can be chosen by the investor for an investment eventually. Depending on how many from the step 2 identified technologies are still worth an investment after the detailed technology assessment, the investor can also invest in a various of different technologies.

Through the application of this assessment approach by investors, future technology trends can be detected and the risk of false investment decisions decreased. Each step of the approach has not to be used sequentially, but can also be applied as own independent assessment tool. Since the approach is currently dealing with a various of technology fields, a constraint for the use to evaluate only one technology field is conceivable, as then the evaluation criteria can be defined more detailed and hence lead to more proper results. As a further consequence, the approach can also be used within firms and R&D organizations.

Another issue for the assessment approach is to increase the level of automation. Currently, the information needed for the pre-filtering process analysis is searched manually. Prospectively, a software program which collects the information from the data bases automatically is desirable.

In the future, the need of efficient assessment methods, tools and approaches will increase for sure, since the present ones consume too much time and effort until a decision is made. Through shorter market life cycles and the rise of dynamic market requirements, an enterprise has to be agile for responding faster to the customers’ needs and desires. Therefore, faster but also more efficient technology assessment methods and approaches will help to deal with this problem by allowing one to derive new strategies within a shorter decision period.

References

Ardilio, A.: Fraunhofer TechnologieRadar: Trends erkennen – Technologien umsetzen, in: **Bullinger, H.-J.:** Fokus Technologiemarkt, Technologiepotenziale identifizieren – Marktchancen realisieren, München 2012a

Ardilio, A.: Fraunhofer MarktExplorer – Heute schon Märkte für morgen erkunden, in: **Bullinger, H.-J.:** Fokus Technologiemarkt, Technologiepotenziale identifizieren – Marktchancen realisieren, München 2012b

Bruhn, M.: Marketing – Grundlagen für Studium und Praxis, 5th edition, Wiesbaden 2001

Bullinger, H.-J.: Einführung in das Technologiemanagement, Stuttgart 1994

Crepea, A.T.: A System Engineering Approach to Technology Assessment, Berkeley 1995

Decker, M. and Ladikas M.: Bridges between Science, Society and Policy, Technology Assessment – Methods and Impacts, Heidelberg 2004

Disselkamp, M.: Innovationsmanagement – Instrumente und Methoden zur Umsetzung im Unternehmen, 2th edition, Wiesbaden 2012

Haag, C.; Schuh, G. and Kreysa, J.: Technologiebewertung, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, Heidelberg 2011

Henriksen, A.D: A technology assessment primer for management of technology, Los Alamos 1997

Klappert, S.; Schuh, G. and Aghassi, S.: Einleitung und Abgrenzung, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011a

Klappert, S.; Schuh, G.; Möller, H. and Nollau, S.: Technologieentwicklung, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011b

Knaf, H. and Bügel, U.: Technologiekompass: Quantitativer Vergleich von Technologieentwicklungen, in: **Bullinger, H.-J.:** Fokus Technologiemarkt, Technologiepotenziale identifizieren – Marktchancen realisieren, München 2012

Kotler, P. and Keller K.L.: A framework for marketing management, Harlow 2016

Lichtenthaler, E.: Technology Intelligence – Improving Technological Decision-Making, in: **Tschirky, H., Jung, H.-H. and Savioz, P.:** Technology and Innovation Management on the move, Zürich 2003

Mankins, J.C.: Technology readiness and risk assessment: A new approach, Ashburn 2009a

Mankins, J.C.: Technology readiness assessments: A retrospective, Ashburn 2009b

Mankins, J.C.: Technology Readiness Levels, A White Paper, NASA headquarter 1995

Mankins, J.C.: Research and Development Degree of Difficulty, A White Paper, NASA headquarter 1998

Mayntz, R., Holm, K. and Hübner, P.: Einführung in die Methoden der empirischen Soziologie, 5^{th} edition, Opladen 1978

Metze, G.: Technologie-Portfolio als Methodik der Inventions- und Innovationsbewertung – Prolegomena zu Metriken für Inventionen und Innovationen, in: **Schmeisser, W.; Mohnkopf, H.; Hartmann, M. and Metze, G.:** Innovationserfolgsrechnung, Berlin 2008

Meyer, A. and Davidson J.H.: Offensives Marketing: Gewinnen mit P.O.I.S.E, Märkte gestalten − Potenziale nutzen, Freiburg 2001

Neemann, C.W. and Schuh, G.: Technologieschutz, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011

Ophey, L.: Entwicklungsmanagement − Methoden in der Produktentwicklung, Heidelberg 2005

Paxmann, A. and Fuchs G.: Der unternehmerische Businessplan – Neue Geschäftsmöglichkeiten entdecken, präsentieren, durchsetzen, Frankfurt/Main 2005

Pillkahn, U.: Die Weisheit der Roulettekugel: Innovation durch Irritation, Erlangen 2013

Pleschak, F. and Ossenkopf, B.: Technologiebewertung, in: **Specht, G.; Beckmann, C. and Amelingmayer, J.:** F&E-Management, 2nd edition, Stuttgart 2002

Pleschak, F.; Sabisch H. and Wupperfeld, U.: Innovationsorientierte kleine und mittelständische Unternehmen – wie sie mit neuen Produkten neue Märkte erschließen, Wiesbaden 1994

Porter, M.: The five competitive forces that shape strategy, Harvard Business Review 86, 2008

Schimpf, S.: Social Software-Supported Technology Monitoring for Custom-Built Products, Stuttgart 2010

Schimpf, S. and Rummel, S.: Bewertung von technologischen Entwicklungen, in: **Warschat, J.; Schimpf, S. and Korell, M.:** Technologien frühzeitig erkennen, Nutzenpotenziale systematisch bewerten, Stuttgart 2015

Schnabel, F. and Rist, M.: Ressourceneffizienzanalyse – Einsparung von Energie und Materialien in Produkten und deren Herstellung, in: **Bullinger, H.-J.:** Fokus Technologiemarkt, Technologiepotenziale identifizieren – Marktchancen realisieren, München 2012

Schuh, G.; Drescher, T.; Beckermann, S. and Schmelter, K.: Technologieverwertung, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011a

Schuh, G.; Klappert, S. and Moll, T.: Ordnungsrahmen Technologiemanagement, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011b

Schuh, G.; Klappert, S. and Orilski, S.: Technologieplanung, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011c

Schuh, G.; Klappert, S.; Schubert J. and Nollau, S.: Grundlagen zum Technologiemanagement, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011d

Schulte-Gehrmann, A.-L.; Klappert, S. and Schuh G.: Technologiestrategie, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011

Siwczyk, Y.: White-Spot-Analyse – ungenutzte Potenziale in der Patentlandschaft aufdecken, in: **Bullinger, H.-J.:** Fokus Technologiemarkt, Technologiepotenziale identifizieren – Marktchancen realisieren, München 2012

Slama, A. and Potinecke, T.: TechAudit: Ein Verfahren zur Erfolgssteigerung von Technologieentwicklungen, in: **Bullinger, H.-J.:** Fokus Technologiemarkt, Technologiepotenziale identifizieren – Marktchancen realisieren, München 2012

Strebel, H.: Innovations- und Technologiemanagement, 2nd edition, Wien 2007

Thomke, S.H., Krishnan, V.V. and Nimgade, A.: Product Development at Dell Computer Corporation, Harvard Business School Case 699-010, 1998

Tran, T.A: Review of Methods and Tools Applied in Technology Assessment Literature, Portland 2007

Warschat, J.; Rüger M. and Hahn, S.: Das Fraunhofer Präsidialprojekt, in: **Bullinger, H.-J.:** Fokus Technologiemarkt, Technologiepotenziale identifizieren − Marktchancen realisieren, München 2012

Wellensiek, G.; Schuh, G.; Hacker, P.A. and Saxler, J.: Technologiefrüherkennung, in: **Schuh, G.; Klappert, S.:** Technologiemanagement, Handbuch Produktion und Management 2, 2nd edition, Heidelberg 2011

Online References

AngelList: Startup platform, https://angel.co/?ref=nav, request of 04.09.2016

Artemis Innovation: About Artemis Innovation, John C. Mankins, http://www.artemisinnovation.com/aboutus.html, request of 11.01.2017

Austrian Angel and Investor Association: About the Austrian Angel and Investor Association, http://www.aaia.at/de/ueber-uns/wer-sind-wir/, request of 14.11.2016

Crunchbase: About Crunchbase, https://about.crunchbase.com/, request of 14.11.2016

Elsevier: About Elsevier, https://www.elsevier.com/about, request of 25.01.2017a

Elsevier: About Scopus, https://www.elsevier.com/solutions/scopus, request of 25.01.2017b

Gartner Inc.: Hype Cycle of emerging technologies, http://www.gartner.com/smarterwithgartner/whats-new-in-gartners-hype-cycle-for-emerging-technologies-2015, request of 19.01.2017

Oddupp: About Oddupp, http://www.oddup.com/about-us, request of 14.11.2016

Scopus: Scopus start page, https://www.scopus.com/home.uri, request of 10.09.2016

Serious Funding: About serious funding, https://www.seriousfunding.be/about-us/, request of 15.11.2016

Slide Hunter: BCG portfolio, http://slidehunter.com/powerpoint-templates/bcg-matrix-template-powerpoint, request of 05.01.2017

Smarter Startup.: Startup Scorecard, http://smarterstartup.org/framework/startup-scorecard, request of 04.11.2016

Smarter Startup.: 6-market dynamics, http://smarterstartup.org/framework/market-dynamics/, request of 31.01.2017

Trendkite: About Trendkite, https://www.trendkite.com/, request of 15.11.2016

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List of Abbreviations

BCG	Boston Consulting Group
Cf.	Confer
CW_k	Criterion weighting (index k defines sub criterion k=1 to k=m)
e.g.	Exempli gratia
EIRMA	European Industrial Research Management Association
ES_{kl}	Evaluation score (index k defines sub criterion k=1 to k=m; index l defines question number l=1 to l=n within sub criterion k)
et al.	et alia (and others)
HAS	Highest achievable score (defined by the score of 5)
IMM	Institute of Innovation and Industrial Management
LAS	Lowest achievable score (defined by the score of 1)
M	Market
MAT	Market attractiveness
NASA	National Aeronautics and Space Administration
NPV	Net present value
PR	Press release
QW_{kl}	Question weighting (index k defines sub criterion k=1 to k=m; index l defines question number l=1 to l=n within sub criterion k)
R&D	Research and development
$R\&D^3$	Research and development degree of difficulty
ROI	Return on investment
SWOT	Strengths weaknesses opportunities threats
T	Technology
TA	Technology assessment
TAT	Technology attractiveness
TM	Technology management
TNV	Technology need value
TRL	Technology readiness level

TRM	Technology risk matrix
TRRA	Technology readiness and risk assessment
U.S.	United States
UAQ	Unsureness of answered questions
$UAQF_{kl}$	Unsureness of answered question factor (index k defines sub criterion k=1 to k=m; index l defines question number l=1 to l=n within sub criterion k)
URL	Uniform resource locator
$	Dollar (United Sates)

Appendix A: Technology Catalog

Table 23: Technology catalog

Technology Catalog

Category	Technology	Application	Source	Publication Year	URL Abstract
Energy Generation	low-head-hydro-power	gorlov-turbine	Science Direct	2014	Theoretical and conditional monitoring of a small three-bladed vertical-axis micro hydro
Construction	3d-printing	on site 3d-printing of houses	Interesting Engineering	2016	http://interestingengineering.com/3d-printed-office-is-the-office-of-the-future/
Nano Technology	nano crystal catalyst	H2 production	Interesting Engineering	2016	http://interestingengineering.com/splitting-water-using-tiny-nanowires/
Nano Technology	nano transistors	micro CPU	Interesting Engineering	2016	http://interestingengineering.com/berkeley-makes-smallest-transistor-ever/
Mobility	hydrogen fuel-cell	e-airplane	Interesting Engineering	2016	http://interestingengineering.com/accelerating-the-future-of-aircraft-with-electricity/
Mobility	hydrogen fuel-cell	e-train	Interesting Engineering	2016	http://interestingengineering.com/worlds-first-zero-emissions-hydrogen-powered-train/
Energy Generation	nuclear fusion	tokamak fusion reactor	Interesting Engineering	2016	http://interestingengineering.com/worlds-largest-fusion-reactor-harness-power-sun/
Energy Generation	microwave energy transmission	interstellar solar-energy harvesting	interesting Engineering	2016	http://interestingengineering.com/using-flying-carpets-to-light-the-world/
Energy Generation	thermo electric materials	solar thermoelectric generator	Interesting Engineering	2016	http://interestingengineering.com/its-solar-power-but-not-as-you-know-it/
Energy Generation	gale turbine	harvesting the power of typhoons and	Interesting Engineering	2016	http://interestingengineering.com/engineers-develop-wind-turbines-harness-typhoons/
Energy Generation	axial-hydro-turbine	tidal hydro power	Interesting Engineering	2016	http://interestingengineering.com/meygen-worlds-largest-tidal-power-project-launched-
Energy Generation	spectrally selective absorber	solar vapor generator	Interesting Engineering	2016	http://interestingengineering.com/solar-vapour-generator-using-bubble-wrap/
Life	reusable space transporter	space tourism	Interesting Engineering	2016	http://interestingengineering.com/live-space-aboard-asgardia/
Advanced Production	pneumatic tubular actuator	soft-grasping	Interesting Engineering	2016	http://interestingengineering.com/borrowing-natures-technology-engineer-precise-
Materials	compostable plastics	compostable shoes	Interesting Engineering	2016	http://interestingengineering.com/heeling-landfills-one-shoe-at-a-time/
Construction	polymer microfibers	ductile concrete	Interesting Engineering	2016	http://interestingengineering.com/new-bendable-concrete-seeks-to-be-stronger-and-
Materials	wood-bleaching	translucent-wood	Interesting Engineering	2016	http://interestingengineering.com/scientists-can-now-create-super-strong-wooden-windows-
Computing	artificial intelligence	machine encryption	Techcrunch	2016	https://techcrunch.com/2016/10/28/googles-ai-creates-its-own-inhuman-encryption/
Computing	natural language understanding	personal shopper	Techcrunch	2016	https://techcrunch.com/2016/11/01/ibm-buys-expert-personal-shopper-from-fluid-to-build-out-

Computing	natural language understanding	personal assistant	Techcrunch	2016	https://techcrunch.com/2016/11/01/rokid-the-assistant-that-can-see-hear-and-sing-raises-50m-
Life	gamification	employee training	Techcrunch	2016	https://techcrunch.com/2016/11/01/axonify-raises-27m-to-gamify-employee-training-
Life	augmented reality	google tango	Techcrunch	2016	https://techcrunch.com/2016/11/01/google-finally-launches-tango/
Life	augmented reality	Microsoft 3d	Techcrunch	2016	https://techcrunch.com/video/microsoft-gm-megan-saunders-discusses-windows-
Life	-	lifelogging	Techcrunch	2016	https://techcrunch.com/2016/10/31/narrative-2/
Advanced Production	terahertz spectroscopy	non invasive early gender definition of	Techcrunch	2016	https://techcrunch.com/2016/10/30/teraegg/
Materials	hemp to graphene	super-capacitors	Techcrunch	2016	https://techcrunch.com/2016/10/27/hemp-cant-get-you-high-but-it-can-get-high-tech/
Health	artificial intelligence	intelligent health diagnostics	Silicon Republic	2016	https://www.siliconrepublic.com/start-ups/kinesis-medtech-funding
Life	augmented reality	personalized books	Silicon Republic	2016	https://www.siliconrepublic.com/start-ups/cleverbooks-ar-3d-publishing-startup-week
Life	autonomous flying drones	security guard for infrastructure	Silicon Republic	2016	https://www.siliconrepublic.com/companies/deutsche-telekom-drone-defence-system
Computing	artificial intelligence	quantum cryptography	Silicon Republic	2016	https://www.siliconrepublic.com/machines/quantum-cryptography-china
Mobility	composite cellular material	morphing airplane wings	Silicon Republic	2016	https://www.siliconrepublic.com/machines/morphing-aeroplane-wing-mit-nasa
Energy Generation	reusable space transporter	interstellar helium3 mining	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/long-march-5-rocket-launch-helium-3
Materials	high anisotropy spin torque resonators	development of new magnetic materials	Silicon Republic	2016	https://www.siliconrepublic.com/machines/amber-transpire-research-contract
Advanced Production	selective laser sintering	3d-printed magnets	Silicon Republic	2016	https://www.siliconrepublic.com/machines/3d-printed-magnets
Advanced Production	KTN-beam deflector	3d printing	Silicon Republic	2016	https://www.siliconrepublic.com/machines/3d-printing-photonics-breakthrough
Advanced Production	fused deposition molding	3d-printing electronics	Silicon Republic	2016	https://www.siliconrepublic.com/machines/3d-printed-heart-chip-harvard
Life	reusable space transporter	commercial space travel	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/iss-expedition-49-cygnus
Energy Generation	piezo electric materials	energy for bio implants	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/tyndall-national-institute-projects-cork
Energy Storage	hybrid-energy storage	super capatteries	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/tyndall-national-institute-projects-cork
Advanced Production	micro transfer printing	creation of integrated components	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/tyndall-national-institute-projects-cork
Communication	photonics integration	fiber broadband data transmission	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/tyndall-national-institute-projects-cork
Computing	cloak of light	photonic processors	Silicon Republic	2016	https://www.siliconrepublic.com/machines/photonics-harry-potter-invisibility-cloak
Computing	dressed qubits	quantum CPU	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/quantum-computer-record-10-fold-stability

Life	sensoric clothing	exoskeletons	Silicon Republic	2016	https://www.siliconrepublic.com/machines/ul-soft-robotics-exoskeleton
Health	bioprospecting	industrializing microorganism	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/extremophiles-discovery-biotech
Computing	t-ray	computer memory	Silicon Republic	2016	https://www.siliconrepublic.com/machines/t-rays-computer-memory-mipt
Life	holography	Microsoft Hololens	Silicon Republic	2016	https://www.siliconrepublic.com/machines/microsoft-hololens-europe
Energy Generation	-	wave energy generator	Silicon Republic	2016	https://www.siliconrepublic.com/innovation/wave-energy-seapower-galway-bay
Mobility	antimatter propulsion	space travel	Kickstarter	2016	https://www.kickstarter.com/projects/2114765394/antimatter-propulsion?ref=category_popula
Energy Generation	-	water powered fuel-cell	Kickstarter	2016	https://www.kickstarter.com/projects/naturesbatterycube/the-cube-portable-water-powered-
Mobility	-	Hyperloop	Kickstarter	2016	https://www.kickstarter.com/projects/1629380361/waterloop-the-canadian-spacex-hyperloop-
Life	virtual reality	gaming	Kickstarter	2016	https://www.kickstarter.com/projects/716502974/oak-turn-your-tabletop-into-an-augmented-
Life	augmented sound	active noise control	Kickstarter	2016	https://www.kickstarter.com/projects/1029411169/tilde-selective-noise-cancelling-
Life	holography	holographic vector display	Kickstarter	2016	https://www.kickstarter.com/projects/2029950924/holovect-holographic-vector-
Life	augmented reality	wearable displays	Kickstarter	2016	https://www.kickstarter.com/projects/1991375881/vufine-the-next-evolution-in-wearable-
Robotics	acoustic source localization	robot orientation	Science Direct	2003	AR_service-robotics_Abstr98
Nano Technology	organic modified montmorillonite (OMMT)	3d-printing nano-composites	Science Direct	2016	Mechanical and thermal properties of ABS/montmorillonite
Computing	ambient intelligence	grid-computing	Science Direct	2014	The Internet of Things vision: Key features, applications and open issues
Advanced Production	astrobiology	bionics	Science Direct	2016	Industry 5.0—The Relevance and Implications of Bionics and Synthetic Biology
Health	artificial neural network	real-time patient data	Science Direct	2016	PCV150 - Real Patients Real Data Systems
Advanced Production	augmented reality	direct production	Science Direct	2016	Towards a griddable distributed manufacturing system with augmented reality interfaces
Robotics	etho-robotics	service robots	Science Direct	2015	Etho robotics: What kind of behaviour can we learn from the animals?
Energy Generation	Haber-Bosch process	biofuels	Science Direct	2016	A system approach in energy renewable energies sources integration in ammonia
Health	bio-informatics	gene-sequencing	Science Direct	2016	Comparative analysis of whole genome sequencing-based telomere length measurement
Health	bio-sensors	bio-markers	Science Direct	2016	Fluorescent biosensors enabled by graphene oxide
Advanced Production	3d-printing	carbon-fiber compounds	Science Direct	2015	Investigation into the Development of an Additive Manufacturing Technique for the
Energy Generation	biogenic methane mining	coal-bed methane	Science Direct	2016	Biogenic methane in shale gas and coal bed methane: A review of current knowledge and gaps

Materials	condensed matter physics	quantum dot composites	Science Direct	2016	Polyaniline/carbon nanotube/CdS quantum dot composites with enhanced
Advanced Production	wire-arc additive manufacturing	iron rich feal intermetallics	Science Direct	2015	Fabrication of iron-rich Fe–Al intermetallics using the wire-arc additive manufacturing process
Energy Generation	reverse osmosis	desalination	Science Direct	2015	Integration of renewables energy system with a high share of wind and photovoltaics
Energy Generation	dye-sensitized solar cell	three-dimensional nitrogen and	Science Direct	2016	One-step synthesis of three-dimensional nitrogen and sulfur co-doped graphene networks as
Advanced Production	equal channel angular extrusion	3d-printing pharmaceutics	Science Direct	2016	Hot-melt extruded filaments based on pharmaceutical grade polymers for 3D printing by
Energy Storage	intelligent food refrigeration	warehouses as intelligent energy hubs	Science Direct	2016	Refrigerated warehouses as intelligent hubs to integrate renewable energy in industrial
Health	alginate quantum dots	gene delivery	Science Direct	2016	Cationic carbon quantum dots derived from alginate for gene delivery: One-step synthesis
Energy Storage	geothermal energy storage	base-load power production	Science Direct	2016	Towards the increased utilisation of geothermal energy storage
Computing	virtual machine monitoring	grid-computing	Science Direct	2016	Virtual Machine Monitoring in Cloud Computing
Robotics	flexible robots	haptic technology	Science Direct	2015	A Novel Tele-Operated Flexible Robot Targeted for Minimally Invasive Robotic Surgery
Health	gene-sequencing	hearing & vision impairment	Science Direct	2016	Chapter 8 - Next Generation Sequencing in Vision and Hearing Impairment
Energy Storage	heat engine	residential building with heat pump	Science Direct	2016	Cost-optimal thermal energy storage system for a residential building with heat pump heating
Advanced Production	automation technology	longwall shearer	Science Direct	2014	Sensing for advancing mining automation technology development
Computing	machine learning	digital memories with pervasive mobile devices	Science Direct	2014	Creating human digital memories with the aid of pervasive mobile devices
Mobility	autonomous conductive charging	electric vehicle charging	Science Direct	2015	Implementation of autonomous distributed V2G to electric vehicle and DC charging system
Mobility	inductive charging	electric vehicle charging	Science Direct	2015	Implementation of autonomous distributed V2G to electric vehicle and DC charging system
Materials	multi-walled carbon nanotubes	mesoporous silica	Science Direct	2016	
Health	micro electrochemical integration	wearable body sensor network	Science Direct	2016	9 - Wearable body sensor network for health care applications
Health	micro-nano-electronics	brain implanted microelectrodes	Science Direct	2014	RFID transceiver for wireless powering brain implanted microelectrodes and
Advanced Production	neutron-damage calculations	non-destructive imaging	Science Direct	2016	Theoretical neutron damage calculations in industrial robotic manipulators used for non-
Energy Generation	horizontal drilling	shale gas exploitation	Science Direct	2016	Chapter Three - Exploration and Drilling in Shale Gas and Oil Reserves
Energy Generation	horizontal drilling	shale oil exploitation	Science Direct	2016	Chapter Three - Exploration and Drilling in Shale Gas and Oil Reserves
Energy Generation	nano hybrid cathode	organic solar cells	Science Direct	2016	In situ implanting carbon nanotube-gold nanoparticles into ZnO as efficient nanohybrid
Nano Technology	plasmon excited quantum dots	nanoimprinted thrombin aptasensor	Science Direct	2015	Nanoimprinted thrombin aptasensor with picomolar sensitivity based on plasmon

Life	internet connected sensors	earthquake early warning systems	Science Direct	2016	Technologies of Internet of Things applied to an Earthquake Early Warning System
Advanced Production	3d-printing	additive manufacturing for shape	Science Direct	2015	Characterization of polyurethane shape memory polymer processed by material
Energy Storage	internet connected sensors	smart grid	Science Direct	2016	Design and implementation of a secure cloud-based billing model for smart meters as an
Energy Storage	gradient flow battery	smart grid	Science Direct	2016	The concentration gradient flow battery as electricity storage Technology energy dissipation
Advanced Production	3d-printing	solid freeform fabrication	Science Direct	2016	The cost of additive manufacturing: machine productivity, economies of scale
Nano Technology	nanorods	super conductivity	Science Direct	2016	Highly efficient yttrium-doped ZnO nanorods for quantum dot-sensitized solar cells
Health	telomere length measurement	genome sequencing	Science Direct	2016	Comparative analysis of whole genome sequencing-based telomere length measurement
Energy Storage	vanadium redox flow battery	electric vehicle	Science Direct	2016	Assessment of the use of vanadium redox flow batteries for energy storage and fast
Energy Storage	vehicle to grid	smart grid	Science Direct	2016	Privacy preservation for V2G networks in smart grid: A survey

Appendix B: Assessment Criteria

Criteria	Description
Applicability	Level of applicability of a specific technology in a component, product, or process.
Application spectrum	Spectrum of the application of the technology to different products or markets.
Applied research team competencies	Level of competencies that are available in the applied research team for the development of a specific technology.
Appropriateness	Factors of the secrecy, accumulated tacit knowledge, and level of complexity of the technology.
Appropriateness of the technology	Potential to protect the technology application against competitors.
Barriers to copy or imitation	Barriers to copy or imitate a specific technology.
Compatibility of the technology	Consistency with values, regulations, and experiences from current products and processes.
Compatibility with existing technologies	Level of compatibility of a technology with technologies that are currently used in the organisation.
Competitive consistency of the technology output	Level of consistency between the output of the technology and the competitive strategy of the organisation.
Competitive intensity	Competitive intensity in the market where the technology is applied.
Competitor's level involved	Competitor's level in the area of application of a specific technology.
Contribution of the technology to value creation	Degree to which the technology contributes to the critical success factors. This is very much guided by the value for the customer due to the high level of customisation of products in the construction industry.
Contribution to customer value creation	Contribution of a technology to value creation for the customer.
Critical mass necessary to adopt the technology	Technologies that can be adopted with an effort that is below a certain critical level (e.g. one person year) should be evaluated differently from those that require a major investment previous to their adoption.
Degree of newness	Degree of newness of a technology compared to substituting technologies in a technological system.
Development team competencies	Level of technological competencies that is available on a specific technology in the development team.
Diffusion in the enterprise	Level of diffusion of the technology in the enterprise.
Dominant design	Degree to which the technology is currently or potentially part of the dominant design in the technological system or on a specific market.
Experience accumulated in the field	Experience that is available on the technology in the organisation.

Criteria	Description
Fundamental research team competencies	Level of competencies on a technology that is available in the research team.
Horizon of availability	Time-frame in which the technology is available for an application.
Impact of technology on competitive issues	Impact of a technology on the competitive situation of an organisation.
Impact on the environment and society	Impact of a technology on society and the environment
Increase of cost-benefit relation for the customer	Level of increase of the cost-benefit relation for the customer through the application of the technology.
Indirect influence of the technology on the sector and the market	Level of indirect influence of the application of the technology on the sector or market.
Interdependencies with other technologies	Links and interdependencies that exist with or towards other technologies throughout the technology life-cycle.
Market acceptance	Acceptance of the technology by the market.
Market sensitivity to technical factors	Sensitivity of the market to the application of new technologies.
Market volume for the technology	Market volume that is opened up by the technology.
Necessary investment until readiness for marketing	Amount of resources that has to be invested in a technology before it can be launched on the market.
Number of stakeholders	Number of stakeholders that are concerned by the application of a specific technology.
Option creation	Potential for further option creation through the application of the technology.
Origin of the assets	Origin of the technology or the know-how that is necessary for its application.
Performance gap *vis-à -vis* alternative technologies	Performance gap between a technology and alternative technologies.
Phase of research	Phase of research in which a technology is located.
Position of the technology in its own life-cycle	Position of a technology in its technology life-cycle.
Potential for progress or further development	Potential for the further development of a technology. This criterion is closely related to the position of the technology in its life-cycle.
Public support for development	Level of support that exists in public for the development of a technology.
R&D resources	R&D resources that are available for the development of a technology.

Criteria	Description
Registered patents	Number of registered patents that exist for a technology within an organisation or outside.
Relatedness to the core business	Degree to which a technology is related to the core business of an organisation.
Relative advantage of the technology	Advantage that can be achieved through the adoption of the technology in current or future products or processes.
Relevance for product and production planning	Relevance of a technology for product and production planning.
Relevance of the technology	Market potential, applicability, and customer value creation.
Relevance of the technology for strategic differentiation	Level of differentiation from competitors that can be achieved through the application of the technology or technology-field.
Risk of the technological development	Technical, commercial, and financial risk linked to a technology development.
Risk of the technology	Technical, commercial and financial risk linked to a technology application.
Sales competences	Ability of the organisation to put the technology on the market.
Scientific technological potential for further development	Level of scientific technological potential of a technology for its further development.
Societal stakes	Level of existing societal stakes in a technology.
Span of application	Span of applications that is opened up by the technology.
State of technology of competitors	Current state of research, development, or application of a technology by competitors.
Synergies	Level of synergies that can be achieved by research, development, or application of a technology.
Technical feasibility	Level of feasibility of a technology.
Technological complexity	Complexity of the technological option concerning its application in a special product or process.
Technological resources	Amount of technological resources that is available in the context of a technology.
Technology acceptance	Acceptance of a specific technology in the organisation.
Technology transfer	Potential of technology transfer of a technology.
Threat of substitute technologies	Threat of substitution of a technology.
Time to market	Time that it requires to place a technology on the market.
Transferability	Ability to transfer a technology from one unit to another.
Trialability of the technology	Ability of the technology to be tested and validated for the application in specific products or processes.

Criteria	Description
Uniqueness of the solution	Ability of the solution to be differentiated from substituting solutions or technologies.
Value of laboratories and equipment	Value of laboratories or equipment that is necessary for research, development, or application of a technology.
Visibility of the technology	Placement of a technology according to the line of visibility.

Figure 41: List of market and technology related criteria for technology evaluation[233]

[233] Schimpf (2010), p.224-228

Appendix C: Questions Technology Attractiveness

Table 24: Question set for possible applications[234]

POSSIBLE APPLICATIONS
The aim of this criterion is to identify if there are multiple options for the usage of the technology. Many possible applications for the technology in potential products increases the attractiveness of the technology and less possible usages decreases the attractiveness, respectively.
QUESTIONS
1) **The technology is very specific and supposed to be for one to two products** To identify the application breadth of the technology ***Evaluation options:*** Strongly agree (1), agree (2), neutral (3), disagree (4), strongly disagree (5) ***Question weighting:*** 30%
2) **Trends for beneficiary influence of the technology can be identified** To identify possible trends and indicators for the evaluated technology which could justify the use of the technology ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 25%
3) **Relevant branches with the need of a beneficiary technology can be identified** To identify branches which already are and branches which could be interested in the future in using the technology ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 35%
4) **Possible product categories which can use the new technology can be identified** To identify potential product categories or products which could use the technology in the future ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 10%

234 Own presentation; Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.330-337; Cf. Henriksen (1997), p.615-633

Table 25: Question set for technology maturity[235]

TECHNOLOGY MATURITY
This criterion determines the maturity of the technology. The following questions are structured in three steps of the maturity process of a technology. Referring the questions to the evaluation of the Technology Readiness Level (TRL), a more mature technology is more attractive and a less mature technology less attractive, respectively.
QUESTIONS
1) The technology has been successfully tested for proof of concept in a laboratory To identify if the principle of the new technology is really working as planned in a laboratory ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 30%
2) A breadboard validation for the prototype unit has been conducted successfully in relevant environment Regarding to question 1, to identify if the new technology is really performing as planned in the relevant environment ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 35%
3) The technology has been used successfully in planned operational environment Followed by question 2, to identify if the technology has already been used successfully in the operational environment ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 35%

[235] Own presentation; Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.330-337; Cf. Henriksen (1997), p.615-633

Table 26: Question set for potential of development[236]

POTENTIAL OF DEVELOPMENT
The objective of this criterion is to identify the potential of development for a technology. The more R&D institutions, the less complex the technology and inexpensive the infrastructure for R&D is, the more attractive the technology will be. Additionally, a "bottleneck" technology for certain applications increases the attractiveness.
QUESTIONS
1) Due to the technology's complexity, specific know-how is necessary to develop the technology To identify if only specialists with detailed know-how are able to develop the technology or if no detailed know-how for developing is necessary ***Evaluation options:*** Strongly agree (1), agree (2), neutral (3), disagree (4), strongly disagree (5) ***Question weighting:*** 30%
2) Research and development institutions put hard efforts in the technology's development To identify how many institutions are interested in technology development since the more institutions, the more likely technological improvement is ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 30%
3) Based on your own experience for estimating the financing of the technology area, infrastructure to do research can be described as costly To identify if expensive infrastructure is necessary to do research and achieve technology development ***Evaluation options:*** Strongly agree (1), agree (2), neutral (3), disagree (4), strongly disagree (5) ***Question weighting:*** 20%
4) The technology represents a bottleneck technology and is needed urgently for performance characteristics or new products To identify if technology improvement is indispensable since enterprises or customers force the development ***Evaluation options:*** Strongly agree (5), agree (4), neutral (3), disagree (2), strongly disagree (1) ***Question weighting:*** 20%

[236] Own presentation; Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.330-337; Cf. Henriksen (1997), p.615-633

Table 27: Question set for alternative technologies[237]

ALTERNATIVE TECHNOLOGIES
This criterion analyses the competitive situation of a technology. If there are many other technologies available instead of using the evaluated one and technology characteristics do not differ in performance, the technology is less attractive. Moreover, substitution products can decrease the attractiveness.
QUESTIONS
1) Based on your own experience for estimating the number of suitable technologies, fill out if many similar technologies are available for the same usage To identify if there are many other existing technologies which fulfill the same purpose ***Evaluation options:*** Strongly agree (1), agree (2), neutral (3), disagree (4), strongly disagree (5) ***Question weighting:*** 35%
2) The technology differs to other technologies in function, quality or efficiency To identify if the technology has advantages against other alternatives ***Evaluation options:*** Strongly agree (5), agree (4), neutral (3), disagree (2), strongly disagree (1) ***Question weighting:*** 35%
3) There is an intensive competition to other technologies To identify if technologies are in competition or if one technology is already the mass application ***Evaluation options:*** Strongly agree (1), agree (2), neutral (3), disagree (4), strongly disagree (5) ***Question weighting:*** 10%
4) A substitute technology can easily replace the firm's technology To identify if a not yet known technology could replace the technology and its application ***Evaluation options:*** Strongly agree (1), agree (2), neutral (3), disagree (4), strongly disagree (5) ***Question weighting:*** 20%

[237] Own presentation; Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.330-337; Cf. Henriksen (1997), p.615-633

Table 28: Question set for dynamic of technology[238]

DYNAMIC OF TECHNOLOGY
The aim of this criterion is to determine the expected lifecycle of the technology, before the technology will be replaced with a new one. The more years for the technology are expected, the more attractive the technology is.
QUESTIONS
1) The technology lifecycle is proposed to be (please select): To identify the replacement time of a technology ***Evaluation options:*** < 1 year (1), 1-3 years (2), 3-5 years (3), 5-7 years (4), > 7 years (5) ***Question weighting:*** 100%

[238] Own presentation; Cf. Schimpf (2010), p.224-228; Cf. Metze (2008), p.325-346; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Mankins (2009a), p.1208-1215; Cf. Haag et al. (2011), p.330-337; Cf. Henriksen (1997), p.615-633

Appendix D: Questions Market Attractiveness

Table 29: Question set for market trend[239]

MARKET TREND
The aim of this criterion is to identify, if the demand within a technology area is increasing. A high market trend increases the market attractiveness, whereas a non existing trend decreases the attractiveness. Moreover, a need from the market for a certain technology also increases the attractiveness.
QUESTIONS
1) A market trend for the technology area can be identified To identify if there is a customer demand for the technology ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 40%
2) The market for the technology is estimated to increase enormously within the next years To identify if the market keeps growing within the next years ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 40%
3) There is an existence of a market need for the specific technology [market pull] To identify if the market forces to develop a new technology for a certain usage ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 20%

239 Own presentation; Cf. Bruhn (2001), p.56-74; Cf. Schimpf (2010), p.224-228; Cf. Mankins (2009a), p.1208-1215; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Metze (2008), p.325-346; Cf. Henriksen (1997), p.615-633

Table 30: Question set for market volume[240]

MARKET VOLUME
This criterions objective is to investigate, how many potential customers for the usage of the new technology in different products are available. The market attractiveness increases the bigger the market volume is and decreases if only a small market volume is tracked down, respectively.
QUESTIONS
1) **The market volume for the overall potential technology usage is identified to be (please make an assumption based on potential market share):** To identify the number of potential customers for the technology usage in different products ***Evaluation options:*** Very large (5), large (4), medium (3), small (2), very small (1) ***Question weighting:*** 100%

[240] Own presentation; Cf. Bruhn (2001), p.56-74; Cf. Schimpf (2010), p.224-228; Cf. Mankins (2009a), p.1208-1215; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Metze (2008), p.325-346; Cf. Henriksen (1997), p.615-633

Table 31: Question set for market quality[241]

MARKET QUALITY
The aim of this criterion is to analyse the quality of the market. The quality includes investigations to market lifecycle, competitive intensity, bargaining power of the buyer and threats of potential substitution products. A low level of the lifecycle, a non-existing competitive situation, a monopoly and no threats of potential product replacements increases the market attractiveness.
QUESTIONS
1) The market lifecycle for the technology can be associated to which phase (please select): To identify the market lifecycle phase of the technology ***Evaluation options:*** Introduction (5), growth (4), maturity (3), saturation (2), decline (1) ***Question weighting:*** 30%
2) Is there an intensive rivalry among firms in the industry? (e.g. number, quality, price) To identify the competitive intensity for technologies with the same usage ***Evaluation options:*** Fully applies (1), largely applies (2), partially applies (3), does rather not apply (4), does not apply at all (5) ***Question weighting:*** 30%
3) The buyer power (e.g. number, size, selection between competitors) is essential for the profitability of the technology To identify if customers have bargaining power for the technology usage or if it offers a monopoly situation ***Evaluation options:*** Fully applies (1), largely applies (2), partially applies (3), does rather not apply (4), does not apply at all (5) ***Question weighting:*** 30%
4) Are there potential threats of substitute products which could replace the technology? To identify if a not yet known technology could replace the technology and its application ***Evaluation options:*** Fully applies (1), largely applies (2), partially applies (3), does rather not apply (4), does not apply at all (5) ***Question weighting:*** 10%

[241] Own presentation; Cf. Bruhn (2001), p.56-74; Cf. Schimpf (2010), p.224-228; Cf. Mankins (2009a), p.1208-1215; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Metze (2008), p.325-346; Cf. Henriksen (1997), p.615-633

Table 32: Question set for market access[242]

MARKET ACCESS
The objective of this criterion is to find ways for the distribution of the technology. If there are early adopters who are interested in the technology, it leads to an increase of the market attractiveness. Moreover, a low time to market increases the attractiveness as well. If there is only a niche market available for the technology usage, it also increases the attractiveness.
QUESTIONS
1) Are there potential early adopters who are interested in using the technology? To identify potential partners who are willing to use the technology in their products ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 50%
2) Based on your own experience for estimating the time to market, the time span for this technology to get to the market would be huge To identify how long it will take until you get your technology implemented in a product to the market ***Evaluation options:*** Fully applies (1), largely applies (2), partially applies (3), does rather not apply (4), does not apply at all (5) ***Question weighting:*** 30%
3) An unfilled niche in consumer marketplace has been identified To identify if only a small group of the market will use the technology ***Evaluation options:*** Fully applies (5), largely applies (4), partially applies (3), does rather not apply (2), does not apply at all (1) ***Question weighting:*** 20%

[242] Own presentation; Cf. Bruhn (2001), p.56-74; Cf. Schimpf (2010), p.224-228; Cf. Mankins (2009a), p.1208-1215; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Metze (2008), p.325-346; Cf. Henriksen (1997), p.615-633

Table 33: Question set for market environment[243]

MARKET ENVIRONMENT
The aim of this criteria is to identify potential problems the market could imply. Bargaining power of suppliers and barriers like legal or environmental issues decreases the attractiveness of the market.
QUESTIONS
1) The supplier power (e.g. number, size, uniqueness, costs, sustainability) is essential for the profitability of the technology To identify if suppliers have bargaining power for resources the technology needs ***Evaluation options:*** Fully applies (1), largely applies (2), partially applies (3), does rather not apply (4), does not apply at all (5) ***Question weighting:*** 50%
2) Are there any barriers (e.g. political, legal, environmental, public, technology patents) to enter the market? To identify if the market implies problems which do not allow to enter the market with the technology ***Evaluation options:*** Fully applies (1), largely applies (2), partially applies (3), does rather not apply (4), does not apply at all (5) ***Question weighting:*** 50%

[243] Own presentation; Cf. Bruhn (2001), p.56-74; Cf. Schimpf (2010), p.224-228; Cf. Mankins (2009a), p.1208-1215; Cf. Schimpf/Rummel (2015), p.46-61; Cf. Metze (2008), p.325-346; Cf. Henriksen (1997), p.615-633