Guidance for environmental technology development of the future: A concise methodology to develop an integrated technology roadmap in the German State of Baden-Württemberg

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Environmental technology is a key sector in the German State of Baden-Württemberg. To support all stakeholders in this sector, an integrated technology roadmap was created for the lead markets "water," "circular economy," and "air" in a collaborative approach between the State Agency Umwelttechnik BW (UTBW) and two research organisations. The objective of such an integrated technology roadmap was to provide a secure base for the agency to plan their future strategic action fields and also to give guidance to relevant stakeholders in the state, especially small and medium-sized companies, R&D institutions, and policy-makers. The roadmap was developed using secondary information from existing research studies and primary information from three workshops involving 20 experts and from conducting 17 expert interviews. The 31 derived market and technology trends have a time horizon of up to 15 years and were documented in trend factsheets. In a systems analysis, a cross-impact analysis was conducted to determine relationships between trends and lead markets. The resulting roadmap was visualised by a professional graphic designer and results were presented on a conference day for practitioners. UTBW will use the determined trends to inform relevant stakeholders and will continue the monitoring of trends. This paper describes the methodology used and the challenges encountered in the course of developing the roadmap.

1. Motivation: strategic guidance for environmental technologies

Environmental technologies have become increasingly important as a result of the growing awareness of the value of environmental protection and resource efficiency. The German State of Baden-Württemberg is one of the most active regions in this area, especially through its vibrant network of small and medium-sized enterprises. Within its centre, is the State Agency, Umwelttechnik BW (UTBW)[1], whose key mission is to support companies in the sector, especially by improving information flow and bringing together research organisations and the industry. In a collaborative project between UTBW, Fraunhofer IAO[2], and Pforzheim University, the challenge was set to create a roadmap that shows the most relevant future

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developments in terms of market and technology.

Among the key objectives of this collaborative project was the development of a roadmap for environmental technologies for the creation of value not only for one specific company but for a sector in specified fields of technology.

The authors have worked on both, the methodology and the structure of the roadmap in order to provide companies in the state with an overview of technology and market trends in the field of environmental technologies with a special focus in the lead markets "water," "circular economy," and "air."

The integrated technology roadmap is meant to provide a secure base for the agency to plan its future strategic action and also to serve as guidance to relevant stakeholders in the state, especially small and medium-sized companies, R&D institutions and policy-makers thus, providing a clearinghouse for industry-relevant information.

A suitable roadmap developed specifically for the state agency and its stakeholders as main target group was not available and therefore, it was the target of the described research project. The results of the roadmap can have an impact on policy discussions in the state, R&D planning in companies, and R&D institutions. The lessons learned from the methodology used can be valuable for practitioners in the field of technology roadmapping, especially in cases where a roadmap is to be established beyond a company or even sectoral borders.

2. Research focus: roadmapping for a state agency

"Environmental technology and resource efficiency" is a major growing field in the State of Baden-Württemberg. Hence, it is a key challenge to strengthening its attractiveness as a business location and support the position of the state as a pioneer in that field. UTBW, the State Agency for Environmental Technologies and Resource Efficiency of the State of Baden-Württemberg initiated a strategic foresight study in order to obtain an overview of the expected technology trends in the field of environmental technologies, especially for small and medium-sized companies in the state. The objective was to obtain an estimate as to which fields are relevant for future actions of the agency. The focus was put on the so-called lead markets "water," "circular economy," and "air."

In this context environmental technology is a technical solution to reduce environmental pollution and to save the environment including the resulting goods and services. This involves technologies for the prevention of environmental damage, end-of-pipe solutions as well as technologies for monitoring and control. The lead market "water" involves the circulation of water from production right up to treatment of sewage. In contrast to other publications, water is defined as a resource here. The lead market "circular economy" contains the four subcategories waste deposition, waste collection, transport, and waste processing. Packaging solutions and usage are not within the scope of this work. Waste air purification and measurement, filter technology and catalysts are included in the lead market "air." Special focus is given to catalysts in factory environments as well as in small-scale furnaces, large combustion plants, power plants, and power generation in general. Traffic emissions, building technology and air conditioning are excluded from this roadmap.

3. Research design: getting interdisciplinary experts involved

Roadmapping is seen as an established methodology both in research and industry (see e.g. Barker & Smith, 1995, p. 22f.; Farrukh, Phaal, & Probert, 2003, p. 7f.; Groenveld, 1997, p. 48f.; Phaal, 2004, p. 130). However, facing the challenge of having various stakeholders involved in the process, combined with a limited amount of resources, only little guidance was found in existing literature on both the level of detail to consider and the procedure to come up with valuable insights for UTBW and other stakeholders.

Based on these challenges, existing roadmapping methodologies have been adapted to create a resource efficient and targeted process considering a time horizon of up to 15 years into the future. Speaking about a highly interconnected system, even across the lead markets, the assets identified were analysed from a system perspective. On a high level, it was classified into the steps shown in Figure 1, combining aspects of existing roadmapping methodologies with those of trend management and inter-organisational strategic planning (see e.g. Barker & Smith, 1995; Carvalho, Fleury, & Lopes, 2013; Laube, 2009; Machate, 2006). Furthermore, the mixture of qualitative methods allowed both, a broad study of potentially relevant topics in each of the lead markets as well as deeper analysis of specified fields in personal interviews with experts coming from industry and research.

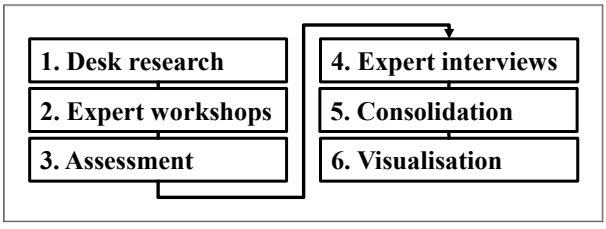

Figure 1. Key steps for the development of the roadmap on environmental technologies.

Due to the restricted amount of resources available combined with the objective of achieving maximum information quality, a combination of secondary and primary information was used to both take benefit from

existing documentations and specify the orientation as well as the details with the help of sector experts. Secondary information is defined here as information that has already been acquired or documented (Bamberg & Baur, 1980, p. 9) in contrast to primary information that is collected with the help of experts in relevant fields.

The six key steps of the methodology are described in the following subsections of this paper.

3.1 Desk research on trends and developments

The objective of this first steps was to get an overview of trends and developments in the field of environmental technologies as a basis for the identification of experts and for the preparation of the workshops. Therefore, secondary information in the lead markets "water," "circular economy," and "air" was collected from existing publications and reviews of recent presentations at conferences.

A previous study had already shown an extensive overview of expected future developments in the field of environmental technologies (see Jörissen et al., 2008). The results were used as a basis for the desk research.

Furthermore, first conversations were started with experts involved in the preparation of existing publications to get insights into the most recent developments and trends. The information collected was used for the set-up of a structure of a technology-market matrix for each lead market. The structures developed were an important input for the workshops to enable targeted and focused discussions and they created the basis for the prioritisation of topics in the lead markets.

3.2 Validating and complementing the broad picture in expert workshops

The input and classification scheme developed based on the desk research was used as a basis for three one-day-long workshops with experts from companies and research organisations in each of the three lead markets. In total, 20 experts actively participated in these three events.

In the first session of each workshop, the major tasks for experts involved:

- The collection of trends in the lead market.
- The allocation of the trend within the classification scheme especially differentiating between market and/or technology trends.
- A more detailed specification of the trend by means of its direction and the reference of relevant organisations or additional experts.

The collection of trends was carried out in the form of a walkthrough fair, where each participant was able to determine trends individually, write them down and get inspired by the input from other participants.

In a second session, all trends collected were discussed and complemented in the entire group to create a common understanding and allow each expert to respond to the trends collected.

The workshops were finalised with a prioritisation of the trends identified based on the participants' perspective.

3.3 First assessment and focusing in an interdisciplinary project team

In a third step, the project team (consisting of the authors and their counterparts at the state agency) assessed the trends and focused them taking the mission and strategy of the state agency into account. Furthermore, first drafts of trend factsheets were developed. Each trend factsheets was structured into the following categories:

- A describing element.
- Drivers of the trend.
- Barriers of the trend.
- The lead market to which the trend belongs.
- Keywords.
- Effect and consequence of the trend.
- Potential application areas, chances and risks especially for technology trends.

Furthermore, the time horizon, the relevance of the trend with respect to the State of Baden-Württemberg as well as the differentiation into technology and market trends is integrated into the description of the trends.

A key aspect in each lead market was the differentiation into technology fields and market segments to which each of the trends identified was allocated.

Within the first assessment, a draft version of the trend fact-sheets was filled out as an input for the investigation in interviews with experts.

3.4 Specification of selected trends in expert interviews

The objective of the expert interviews was to specify the identified trends in more detail and to evaluate their relevance to the field. To reach this objective, a semi-structured interview guideline was set-up, structured according to the trends identified in each lead market.

17 experts were identified by the project team and their expertise was attributed to the trends. The selection of experts was conducted with respect to the following aspect:

- Every expert should have market and/or technology expertise in at least two of the trends.
- There is input from at least two experts for every trend.

Experts were then contacted and interviews with them were conducted in personal conversation or over the telephone.

In these interviews, the trends which matched with

the expertise of the expert were presented and the following questions were asked:

- Do you agree with the trend in general? Could you please describe the trend in your own words?
- Which issues belong to the stated trend?
- Which drivers are reinforcing the trend?
- Are there barriers obstructing the trend?
- At what point are we today? How will it develop in future? When do you think will the trend occur/have an impact (in the State of Baden-Württemberg)?
- How important is the trend for the State of Baden-Württemberg (especially its industry and R&D institutions)?

The results were then documented and collected information condensed in the trend factsheets.

3.5 Consolidation of trend hypotheses

The collected trends were analysed in their entirety. Thereafter, their relevance and implications regarding the State of Baden-Württemberg were discussed and classified. In order to assess the relevance following criteria were used:

- Economic potential
- Wide range of applications
- High potential to reduce environmental stress
- High technological strength in the State of Baden-Württemberg (or backlog demand compared to others)
- Relevance for target groups of UTBW

The trends with a low degree of relevance with respect to these categories or trends that were not acknowledged by the experts were sorted out. Each of the trends was finally described in more detail in a trend factsheet.

In addition to the more detailed description of each trend, a system analysis was carried out to identify interrelationships within and between each of the lead markets resulting in the identification of the most important trends in the area of environmental technologies. The relationships between each of the trends were determined in a cross-impact-analysis.

3.6 Roadmap visualisation

Roadmaps can highly differ regarding their visualisation. Different proposals for their visualisation can be found for example, in (Kerr & Phaal, 2015). Following the objective that the roadmap will be used by UTBW for strategic guidance and by SMEs for orientation about technology and market developments, different visualisation concepts were drafted and were complemented by a force-atlas diagram representing the results of the cross-impact-analysis (see Figure 2).

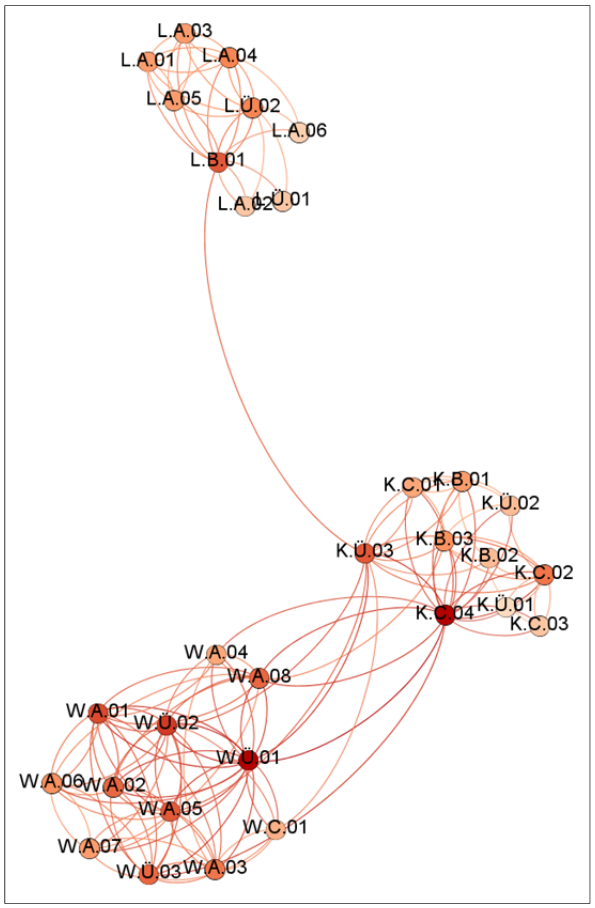

Figure 2. Force-atlas diagram of interdependencies between trends based on the cross-impact-analysis executed (see for example Khokhar, 2015, p. 70f).

With the combined information from the trend factsheets, the system analysis together with the options for roadmap visualisation, the final roadmap was visualised by a professional graphic designer (see chapter 3).

To present the developed roadmap, a conference day for practitioners was organised by UTBW at which the results of the roadmap were presented briefly by the project team. For each of the three lead markets, three selected trends were presented in more detail. These presentations were not conducted by the project team that developed the roadmap, but rather by companies and research institutes that are working in the field of the respective trend. As a result, the subject matter was shown in a more concrete way to participants.

In addition, a software tool was programmed by an external solution provider which contains all the trend factsheets, visualisations, and the assessment of the trends (such as relevance and time horizon). The tool facilitates the filtering of information in order to provide a visualisation of selected trend content for companies requesting it. The tool also allows for the updating of the trend information and thus, helps UTBW to continuously work with the trends.

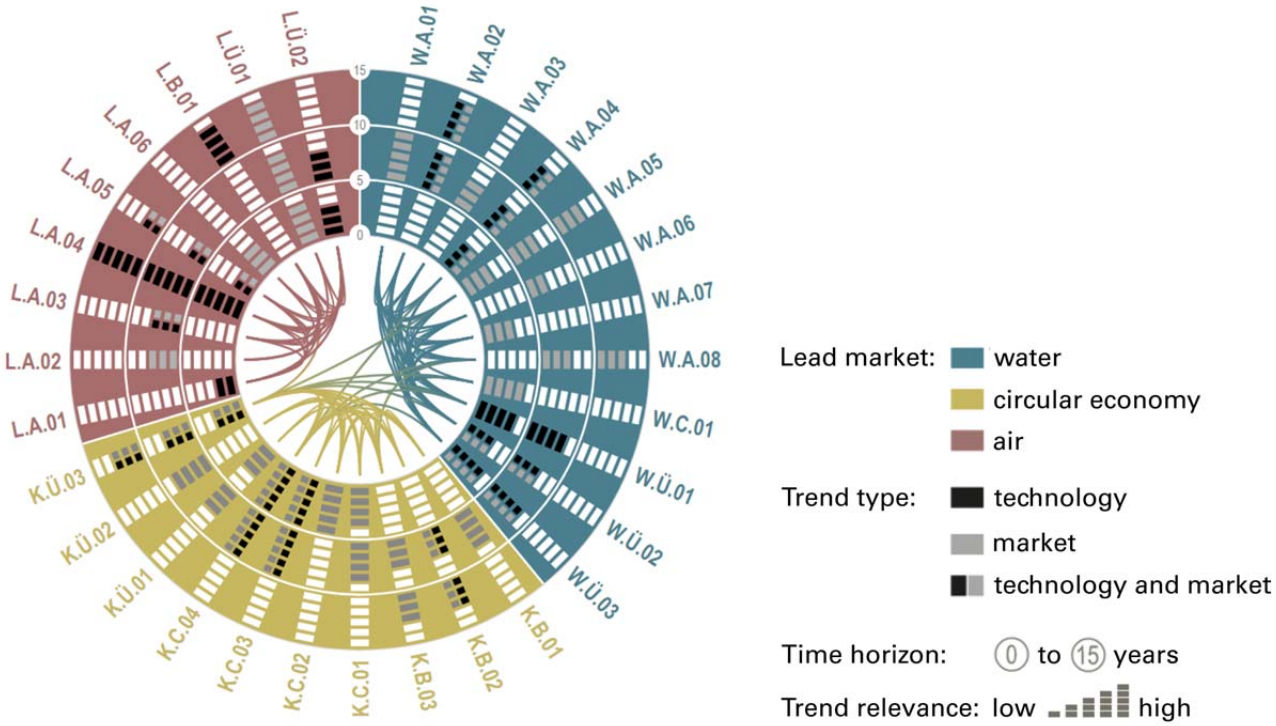

Figure 3. Roadmap Environmental Technologies 2030 with a regional focus at the German State of Baden-Württemberg (Umwelttechnik BW, 2017).

4. Research outcomes: guidance for academics and practitioners

The conducted project (consisting of a concise number of working steps) resulted in a visualised roadmap which will then be transferred to the general public, policymakers and companies in the State of Baden-Württemberg.

The roadmap consists of 31 trends in the three lead markets "water," "circular economy," and "air."

The lead market "water" (abbreviated with the letter "W" for the German term "Wasser") was structured into the following fields:

- A: waste water treatments (8 trends identified)
- B: efficient water use
- C: water procurement and purification (1 trend identified)
- D: water infrastructure
- E: water protection
- Ü: cross-sectional field (3 trends identified).

The lead market "circular economy" (abbreviated with the letter "K" for the German term "Kreislaufwirtschaft") was structured into the following fields:

- A: waste deposition,
- B: waste transport and collection (3 trends),
- C: waste processing (4 trends)
- Ü: cross-sectional field (3 trends).

The lead market "air" (abbreviated with the letter "L" for the German term "Luft") was structured into the following fields:

- A: waste air purification and measurement (6 trends),
- B: filter technology and catalysts (1 trend),
- C: traffic emissions,
- Ü: cross-sectional field (2 trends).

Consequently, the trends in the roadmap were given numbers attributing them to a lead market and a field in a lead market, e.g. "W.A.01" or "K.C.01."

The developed roadmap is shown in Figure 3 including the indication of main graphical elements. The interdependencies identified in the system analysis are represented in the centre of the roadmap. The visualisation in a radar-chart reflects the focus of the roadmap on trend-hypothesis rather than products or the following high-level allocation of these trends within the timeline.

The state agency UTBW decided that the detailed list of trends will only be made available to selected actors in the State of Baden-Württemberg at this point. Hence, the full list of trends cannot be shown. Examples of identified trends are:

- W.A.01 Relevance of energy efficiency for public wastewater treatment plants will increase (market trend, 5 to 10 years, high relevance)
- W.Ü.1 Effectiveness and efficiency of physical separation processes will improve (technology trend, 0 to 10 years, relevance medium-high)
- K.C.02 Electric / electronic waste recycling will be applied increasingly (market trend, 0 to 5 years, high relevance)

Figure 4. Example for a trend-factsheet representing each lead market out of the overall of 31 trend factsheets described (Umwelttechnik BW, 2017).

- K. C.03 Recycling of photovoltaics: application and technology development will both increase (market and technology trends, 0 to 10 years, high relevance)
- L.A.03 Processes to separate mercury will be developed further and will be applied more (market and technology relevance, 5 to 10 years, relevance medium-high)
- L.Ü.01 Further diffusion of processes for energy recovery from exhaust gas (market trend, 0 to 15 years, relevance medium-high)

The description of the 31 trends in the trend-factsheet as explained above is illustrated in three examples in Figure 4. In these factsheets, each trend is described in one or two paragraphs and keywords are depicted.

The description of the methodology can be the basis for similar roadmap projects in other fields. It was conducted independently of specific projects in R&D or market aspects. As opposed to other projects, where the researchers take over the research tasks completely, the working situation was different, here. The state agency UTBW actively supported the project by being involved directly with the project team. This was seen as crucial in order to facilitate a process which was relatively resource-restricted. Through the involvement of relevant actors in workshops and expert interviews, the environmental technology community was included in the roadmapping process in an efficient manner. The challenge of creating a roadmap not for one specific company, but for a set of different stakeholders with varying interests lead to the further development of the roadmap methodology and builds upon insights gained during a study on the practical application of roadmapping in industry (Abele & Schimpf, 2016). In addition to the support of stakeholders, it also helped to align cooperative and support activities coordinated and carried out by the state agency UTBW and to identify future fields of action through a dedicated white spot analysis.

5. Conclusions and outlook

An integrated technology roadmap for environmental technologies in the lead markets “water,” “circular economy,” and “air” was created in a collaborative approach between the state agency UTBW and two research institutes in order to support all stakeholders in the environmental technology sector of the German State of Baden-Württemberg.

Due to limited resources available, the process of creating the roadmap had to be adapted. UTBW as the contracting authority actively supported the project team in addition to supervising the project. An extensive desk research provided valuable secondary information. Primary information was obtained from three workshops involving 20 experts along with 17 additional expert interviews. The resulting roadmap was visualised by a professional graphic designer.

The roadmap consists of 31 market and technology trends with a time horizon of up to 15 years in the lead markets “water,” “circular economy,” and “air.” The results of the roadmap were presented on a conference day for practitioners. Selected trends were presented by companies and research institutes who are directly impacted by the trend and not the roadmap project team. This helped to convey the trends in more depth and with more relevance to the audience. The trends will be used by UTBW to inform relevant stakeholders.

In the context of the work presented, potentials for additional research unveiled in the following areas:

- Development of roadmapping standards enabling an improved exchange of information and cross-organisational use of roadmaps.
- Improved guidance for technology and market assessment independently from specific products.
- Lean and semi-automated processes for most efficient set-up and update of roadmaps.

The State Agency UTBW will continue the monitoring of technology and market trends in the three lead markets. The systematisation of the trends will then provide the basis to structure its strategic orientation. The objective is to collect information and then re-evaluate trends statements once or twice a year, followed by a discussion about required action.

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