From Integration to Interpretation: Translating ForSTI into Strategies

9

9.1 Introduction

One of the key features of ForSTI is that it is a policy and action-oriented activity. Therefore, the process does not simply end with the description of preferable futures, but goes to the next levels on the ways of formulating and implementing strategies and policies, and planning and allocating resources for successful implementation.

The task of determining a preferable state of the future, and the ways of achieving this, is a multifaceted process, where there are a variety of worldviews and expectations to be negotiated. This can be considered as a transition from a more exploratory and divergent thinking mode to a more normative and convergent mode of thinking in the ForSTI process.[1] At this phase of the activity, decisions on the desired future system need to be aligned with normative goals and values. An inclusive process, where the creative exchange of ideas and information sharing among participants is experienced, is beneficial. The definition of the 'most desirable' future system is a matter of 'prioritisation'. The end product of this phase is an agreed model of the future. Methods like Delphi (Chap. 6), Cross Impact Analysis (CIA—Chap. 8), Multi-Criteria Analysis (MCA), SWOT and/or Cost/Benefit Analysis (CBA) can be considered among the methods to support this process. Some of these methods have been referred in the earlier chapters of the book. In this chapter, we will particularly focus on CBA and MCA, and then consider the techniques of Critical/Key Technologies, before moving on to the roadmapping approach.

Roadmapping has become one of the most frequently used tools for bridging the future with the present. This is mainly because the method encompasses the key features of ForSTI, including: (1) linking the future with the present, (2) examining

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[1] Recall that we do not see exploratory and divergent, or normative and convergent, approaches as inextricably bound together. However, the loose association within each of these "couplets" holds up fairly well as a description of different steps of the ForSTI process.

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multiple alternatives for achieving desired futures, (3) providing participation through an interactive process. Roadmaps are used to ***guide decisions*** on research, development and innovation by providing information through graphics and visualisations instead of lengthy reports—though short reports may always accompany roadmaps for further information on key assumptions, description and elaboration of the components of the roadmap as well as providing policy and strategy recommendations. Thus roadmaps are easily understood by all parties involved and helping ensure discussions are informed, open and objective.

9.2 Assessment Methods

9.2.1 Cost-Benefit and Multi-criteria Analysis

ForSTI activities seek to inform stakeholders about decisions they could be, or actually are, making. While people will generally not want to follow advice blindly, and while policymakers and senior managers will generally want to feel that THEY are the ones making the decision, often they want more than just information about the options that might be available and the advantages and disadvantages associated with them. Decision-makers often demand that advice involves proposals as to what to do, which options to prioritise—even if they may also want to overrule such advice in the light of their own considerations.

Numerous techniques have been developed to help decision-makers choose between alternative options. When we put it this way, it is already apparent that these approaches presuppose that we have a set of alternative options. This may not be the case—or there may be considerable scope for modifying or tailoring options, for combining elements of different options, and so on. (We are comparing Option A against option B, but what about Option A + B—there may be multiplier effects—or some compromise that is 50 % A and 50 % B?) It may also be that options are not strictly equivalent, for example in terms of the level of "granularity" they refer to. For example, comparing Option A (fund research into new approaches to achieving greater energy efficiency) against Option B (fund a single centre to research into the applications of gene therapy to skin cancer), or Option A (undertake wide-ranging public consultations about the desirable future for the health and social care system) against Option B (survey staff attitudes to use of smart cards in electronic patient health records), are not just comparing chalk with cheese—they are more like comparing one piece of chalk with a whole shop full of different cheeses.

Still, decision makers may be presented with a limited range of options, for example a set of priority areas for research arising out of a ForSTI exercise. In many conventional planning exercises, the criteria being employed are strictly economic ones. A **Cost-Benefit Analysis** (CBA) simply seeks to examine what the costs of various options are, and what their benefits are, expressed in financial terms—and with discount rates applied to take into account the estimates as to when expenses will be incurred and when the rewards will become apparent. Many decisions as to (for example) large infrastructural projects, are based on such an approach.[2] The approach has been often criticised for its limitations. (cf. Ackerman 2008—who outlines six criticisms of the approach—Kelman 1981; Rosenhead and Thunhurst 1979). For example, the value judgements necessarily creep in when putting monetary values on, say, ecological damage or cultural heritage, on the time of non-employed people as that of senior managers. Massive future costs may appear negligible simply because they are remote—Linstone (1973) notably showed that the catastrophes predicted by *Limits to Growth* were discounted to being practically meaningless because they would only happen in future decades hence. CBA can be used in more sophisticated ways than simply providing an overall score for each option, though. Costs can be plotted on one axis and benefits on the other, for example, to give a two-dimensional mapping of the alternative options in terms of these two dimensions. The options can be represented not by dots or points, but as fuzzier oval or circle shapes, to indicate the level of uncertainty associated with the cost-benefit judgements. Risks can be indicated, for example by plotting each option in two locations—one of which assumes successful implementation, one which assumes that non-negligible risks of failure (say, those with more than a 1 in 10 chance of happening) do occur. Different discount rates can be employed, with arrows emerging from the dots to indicate the ways in which the cost-benefit ratios would change when future events are valued in different ways. While most CBAs do not adopt such approaches, it makes sense for long-term ForSTI analysis to consider presenting any CBA results in more elaborate ways than simply scoring benefits minus costs. Even so, the methodology is limited by its use of a single criterion for assessing value.

Multiple Criteria Analysis (MCA—also known as multi-criteria analysis and other variations on the theme) is employed when monetary values are not considered to be sufficient for representing the objectives and impacts of decisions. For a description of the approach, and some alternative ways of applying it, see Department for Communities and Local Government (2009). Several techniques are in existence, but in common they involve scoring the alternative options against a series of defined criteria; and having users indicate the relative importance of each criterion in numerical form, so that the scores that each achieves can be weighed in terms of importance. The most common practice is then to use "importance" as the overriding criterion, and reduce assessments on the different criteria to a single measure of importance (as contrasted with CBA's use of monetary values). So what most often is done, is to compute the overall value attached to each outcome (how much will X happen and how important is X), and thus rank the options in terms of their (non-monetary) cost-benefit appraisal. This assumes that the values are computable (what if, for instance, infinite value is placed on some attribute such as "survival of the human race"?). However, the approach does not need to culminate

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[2] For a set of resources on using cost-benefit analysis, with worked examples, see the "Green Book" website at https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent (accessed 10/12/2014).

in a single score of options on a single dimension. It is equally possible to contrast a set of options in terms of how each fares in terms of different value criteria. Thus the form that the advice takes might go along lines such as: "if your goal is to maximise this sort of outcomes, then these options look most viable, while if you in contrast prefer these other outcomes, then these options rise to the top". The user can then make decisions that take into account, for example, the need to avoid particular types of extreme outcome, the need to balance between various values, and so on. It is also possible to use some statistical analyses here—which outcomes are more often positively or negatively associated with each other; which options look most similar in terms of outcomes. It is also possible to combine mixtures of options (if they are not mutually exclusive), in the form of different "scenarios" (in the terminology we introduced earlier, we call these profiles) that can be compared with each other, as Gough and Shackley (2006) do.

Gough and Shackley (2006) detail this study's application of MCA to some STI options. Their work examined a number of possible approaches to Carbon Capture and Storage (focusing on ways in which CO_2 might be stored to avoid further climate change hazards from emissions). They aimed at doing more than just selecting the "winner" from a set of options. One feature of their use of MCA was to provide insight into the expectations and preferences of those providing the information for the project; this gave the researchers the ability to better 'map' the key issues shaping the prospects for future development of the technology they were considering—. The MCA study was conducted in two stages.

The first stage was "reservoir assessment", where criteria relevant to assessing a number of options for storage of CO_2 were compared (These options were offshore oil and gas fields; offshore saline aquifers within traps and outside traps; and on-shore sites). These options were assessed against a first set of criteria, dealing with the effectiveness of the technology. This set was developed in an iterative process with expert respondents (geologists from the British Geological Survey). The authors reported that their experts found it much easier to generate ideas when they were commenting on and adding to a list of potential criteria provided to them by the study team. In contrast, having to generate their own criteria on a blank slate was challenging. (We have noted similar tendencies in other contexts. The message is: do some preparatory work and provide your experts with, at least, a few examples!) With the experts, a set of default scores was developed for the reservoir options; disagreements demonstrated where there were areas of scientific uncertainty and controversy. Other study participants, if unconfident or uncomfortable with assigning their own scores to the options, could use these default scores (Most of the non-experts used these defaults, thus being able to assign weights to the value criteria, without needing to have developed their own in-depth understanding of the storage options).

All participants were asked to weigh the criteria in value terms, i.e. how important each was. Thus the relative 'performance' of each reservoir option could be calculated, for each participant, on the basis of the options' scores and weights. This approach is using the value weighing placed on each criterion in a way rather like the use of simple monetary values assigned in CBA. It still requires some assumptions about the validity of the arithmetic operations of multiplication and addition that are employed to reach the estimates of how well, overall, the options perform against the value criteria. It could be argued by CBA proponents that we can be more confident that adding up two monetary values provides a coherent result, than we can about adding up two ratings of importance. However, MCA does at least not assume that everything can be assigned a monetary value, and can be used so that decision-makers can consider what values they would assign to particular criteria—or to particular combinations of outcomes in terms of different criteria. The sort of rationalistic approach used by MCA has been shown to have some predictive utility in examining how individuals' attitudes relate to their expectations and values—attitudes reflect beliefs about the likely consequences of choices for variously valued outcome criteria (Ajzen 1988). But we also know from behavioural economics that psycho-logic is often not a simple mirror of rational logic, for instance when risks are being assessed.[3]

Figure 9.1a, b display some results from this first stage analysis; they present the default assessments of the options in terms of the first set of criteria, and the overall views of the options from different stakeholders.

The study discusses the underlying reasons for the assessments, and the divergence of views. As the lower part of Fig. 9.1 indicates, there appears to have been a moderate degree of agreement as to the best and worst options. In a second stage of the study, alternative scenarios (that were described in terms of different extent of development of the four options) were compared. Further criteria were now introduced, going beyond assessing the effectiveness of the technological options. These were: cost, infrastructure change required, lifestyle changes required, security of supply, environmental impacts, credibility (of the scenario), risk of major disasters, international/distributional effects. Again the study participants assessed the relative importance of the criteria, so that a set of scenarios featuring different combinations of the technological options could be compared. As in many real life situations, some mixture of options is likely—emphasis on a single technological solution typically carries substantial costs in terms of one or other criterion, and substantial risks if things go wrong.

This was not a large scale exercise, but does demonstrate how quite simple methods (the only technical support required was a spreadsheet) can be used to gain insight and provide rich information for policymakers and stakeholders. While in some situations a clear and decisive answer will be sought—which option should we go for?—there are, fortunately, many cases where debate can be furthered, and

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[3] The literature on these topics is vast. For an introduction to behavioural economics, see Kahneman (2003); one of many efforts to assess and explain public perceptions of emerging technologies is Kahan et al. (2007); efforts to explicate key risk issues for policymakers is Annual Report of the Government Chief Scientific Adviser (2014) and Williamson and Weyman (2005). Foresight Programme commissioned an excellent "Science Review Summary: Public Perception of Risk" (by J.R. Eiser, dated 2004); this is still accessible online from other repositories, such as http://web-archive-net.com/page/789210/2012-11-29/http://www.bis.gov.uk/files/file15017.pdf

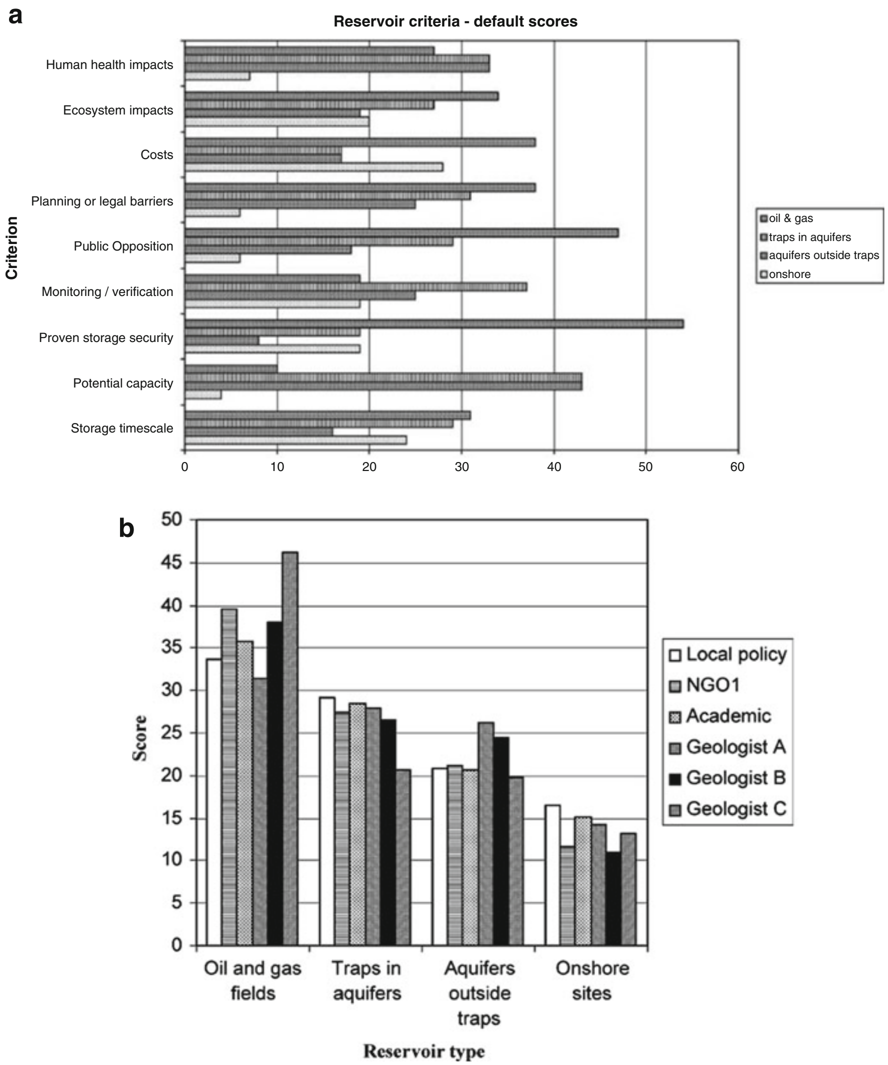

Fig. 9.1 (**a**, **b**) Stakeholder assessment of different carbon storage options

decisions better informed, by systematic provision of evidence about different criteria and outcomes.

9.2.2 Other Assessment Approaches

There are many other efforts to develop tools useful for decision making where we are confronting multiple criteria and (often) some degrees of uncertainty. The field of Operations Research is a rich source of these, along with the fast-evolving area of Decision support Systems. Probably the best-known method after CBA and MCA is the Analytic Hierarchy Process (AHP—see Vaidya and Kumar 2006).[4] Like MCA, this suggests that we evaluate options in terms of multiple criteria. In a twist that makes it particularly suitable for group discussions, the approach usually involves making pairwise comparisons between criteria; how do these criteria impact upon the overall assessment of the option—or, indeed, on some higher-order criterion (For example, we might take economic development to be the overall goal; this is assessed in terms of criteria such as employment, wealth creation, and so on; employment is assessed in terms of job creation, quality of jobs, etc. It is possible to have multiple layers in such an approach—which would then require subgroups to work on them. With multiple layers and such subgroup judgements, though, there is much scope for inconsistency to creep in). Numerical weights are then assigned to the criteria, and the options assessed in terms of their (likely) performance in terms of these. A convenient short description of AHP, some of the main criticisms of the approach, and its relation to other tools is provided by the Department for Communities and Local Government (2009).

9.3 Prioritisation: Critical Technologies

This section will outline the Critical Technologies approach, which has been one of the most common ways of undertaking ForSTI in a number of countries—notably France and the United States. In some languages, the word “critical” implies “catastrophe”, and therefore the wording “key technologies” is used instead, for example Technologies Clés in France (Louvet 2000) or—Schlüsseltechnologien in Germany (BMBF 2003). Despite the name, the meaning is always the same—technologies which have a strong potential to influence national competitiveness and quality of life. Thus the approach involves applying criteria to measure the relevance or criticality of particular technologies to these goals (The term springs from the American identification of strategic and critical materials in 1940, referring to materials needed for the US Army which were either not produced at all or produced in inadequate quantity, respectively, in the US (Miller 2007). The term continued to be used, for example in the 1950s it signified materials where 5-year stocks should be held in the case of military conflicts. In the 1980s the idea began to be applied to materials that critical to some economic sectors, and to technologies as well, that were widely used across the economy).

In the ForSTI context, we are concerned less with those technologies that are of current importance, and more with those that are liable to be of high significance in the future. Resources that are invested in such technologies are anticipated to lead to significant returns in various applications in the future—they represent

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[4] Some similar approaches in ForSTI work are reviewed in Lee et al. (2008); see also Martin and Daim (2012) for application in a roadmapping context.

technological opportunities to create beneficial products and/or processes in terms of economy and/or quality of life outcomes. For example, we can anticipate that some developments of so-called generic technologies (those that are widely used, that underpin many sorts of applications, that provide key components for more complex products and systems) are liable to be critical. Prospective developments in artificial intelligence may be critical, for instance, to a wide range of Information Technology (IT) applications—from autonomous vehicles and robotics, through to decision support systems and ways of providing cognitive support to people confronted with more real-time data than they can process. So when there is rapid technological development in a generic technology—like new IT, genomics and biotechnologies, nanotechnologies, etc.—there may well be many critical technologies emerging.

9.3.1 Critical/Key Technologies

Bimber and Popper (1994) suggested that three criteria would need to be met for a technology to be considered as critical. It should be:

- **Policy-relevant**—policymakers should be able to see to what the technologies are critical for, and where there may be points of political intervention that would increase capacity vis-a-vis the technologies and the needs they address. Bimber and Popper mention paying attention to such issues as R&D, commercialisation, dissemination and utilisation of technologies. They note that some technologies upon which countries rely may nevertheless not be critical is they are easily obtainable on the world market: lack of self-sufficiency is only grounds for concern if there is a realistic prospect of lack of access to commercially available products in the global marketplace.
- **Discriminating**—though "grey zones" are common whenever we are confronted with uncertainty, Bimber and Popper argue for a clear distinction between critical and non-critical technologies, and application of methods that will place candidate technologies clearly in one or other group. This reflects their concern that every advanced product or process might be touted as critical, and perhaps the fear that things that have been hyped in the media might be automatically assessed in this way. Many things that attract media coverage will only be important (if at all) in the very long-term, or in very specialised applications. (Likewise, technologies that are "state of the art" may not be relevant to policy, even though they attract a great deal of attention.) Bimber and Popper also draw attention to the need to consider the level of aggregation (or granularity) that we are using. A grouping that is too broad is liable to include non-critical developments of a generic technology, for example, alongside more critical areas of application or technological progress.
- **Reproducible**—a transparent methodology should be used to develop results, so that it would in principle be possible for others to follow the same procedures and reach similar conclusions. (In practice, this may not always be possible,

simply because experts might not want to answer the same questions twice—or they might be influenced by the published results of an earlier exercise.) A clear exposition of the methods employed is important for giving confidence in the results, in learning from any problems that were encountered, and for being able to compare the outcomes of different exercises.

The critical technologies approach, then, typically aims at generating a list of such technologies, a justification of this list, and clear specification of related policy actions that follow from this. While the basic outcome is a prioritisation of critical technologies, the assessment of what is and is not critical, and what the action implications of this are, inevitably implies some analysis of the national innovation system (or of the system for whatever unit of analysis is being considered – it would even be possible to do city-level analysis, and there are many regions in some countries that are larger in demographic and economic terms than the smaller countries of the European Union, for example).

Prioritisation of R&D fields has long been an objective—often the leading objective—of ForSTI exercises. The goal may be simply that of deciding where to allocate public funds, or it may involve stimulating wider awareness (especially in industry and the research community) of key technologies. Identification of policy measures can be a valuable input to discussion of STI policy mixes, as could be the discussion of what criteria are relevant for assessing priorities.

9.3.2 Applying the Critical Technologies Method

As with most ForSTI methods, there are many ways in which this approach can be implemented. Almost invariably they depend, however, on consultation with experts in order to form judgements. Often a relatively informal method has been used—a panel has selected the key technologies, after some discussion of criteria, usually drawing upon some overview of developments in different technology fields (such overviews prepared in the course of UK Foresight are the Technology and Innovation Futures reports, which drew on interviews with a range of experts).[5] More formal approaches typically involving surveying experts, and the first tasks will thus be (a) designing the survey and (b) locating key experts to whom the survey should be sent.

Even in the case of a panel-based approach, involving a limited number of experts and a narrow consultation approach, the sponsor will need to choose panel members. If there is broader consultation, for example by a survey, then some core group will still need to locate key experts and interpret results. Broader consultation typically takes more time, but the loss of speed may be offset by the gain in legitimacy from examining wider views.

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[5] Available at https://www.gov.uk/government/publications/technology-and-innovation-futures-uk-growth-opportunities-for-the-2020s (Accessed on: 02.11.2015).

The survey (or even the discussion within a small group) needs to work on the basis of some initial list of technologies. In a Delphi-type approach, this list may be derived from a more open-ended survey, or by other approaches such as using lists developed in previous ForSTI studies (especially those conducted fairly recently in similar territories), from interviews, or via a wide-ranging review of literature; in any case it will require fine-tuning by a core group or expert panels to develop a list that is clear and concise, readily understandable, and at the right level of granularity.

The survey (or group discussion) will need to embody some criteria for prioritisation—and again, in a survey these will need to be very clear and concise. Thus in the Delphi study of the first UK exercise, respondents were invited not only to indicate when they thought particular technologies would be realised, but also to rate each example in terms of its contribution to "wealth creation" and "the quality of life" (to be precise, respondents voted about specific "topics", most of which involved STI, but a few of which dealt with topics such as regulations, social developments, etc.). A rating scale was employed with four scale points ranging from "negative", through "neutral" and "positive", to "very positive". Once survey results had been accumulated, each topic could be located on a two dimensional graph comparing the average ratings on each objective (In some STI areas—such as health—the two tended to be highly correlated, e.g. high contribution to wealth creation was associated with high quality of life impact. In some areas, such as transport, the association was much lower). The plotting of topics on these dimensions clearly informed the final judgements of the Foresight Steering Group as to priority fields for study; since technologies were considered in terms of "attractiveness", reflecting the score on these dimensions.

However another variable comes into play—how feasible it is that the technology can be developed within the national innovation system. In the current approach adopted in France, key technologies are defined as being those that are 'attractive' (have a potential for practical implementation in 5–10 years ahead) and where France has competitive advantages (in terms of the presence and performance of enterprises or research laboratories, the development of innovation ecosystems, and so on).[6] The UK Delphi solicited ratings about the level of capability (or feasibility) in the UK to undertake the science and the commercial exploitation of the various topics considered, and this also informed the final judgements. A representation of the prioritisation scheme is given in Fig. 9.2.[7]

A two-dimensional plot could be obtained, using a combination of the impact and the capability scales (Fig. 9.3).

In the figure, critical technologies are located on the top right corner of the figure. These are the technologies with the highest Attractiveness/Importance and Capability/Feasibility rankings. As they are both attractive/important and at the

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[6] France has had earlier rounds of "Key Technology" exercises in the 1990s and at the turn of the century—see Barré (2008). For the recent exercise, see Ministere de l'Economie, de Finance et de l'Industrie (2015).

[7] This scheme was also used in the Czech ForSTI exercise, which will be mentioned briefly below.

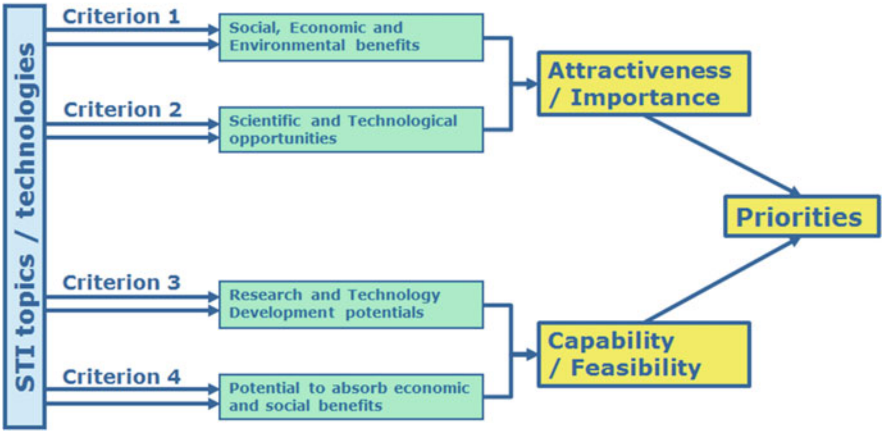

Fig. 9.2 Prioritisation scheme. Adapted from Klusacek (2003)

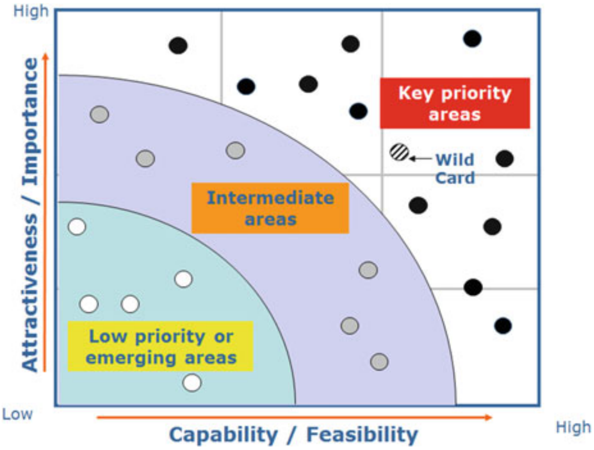

Fig. 9.3 Attractiveness/Feasibility matrix

same time feasible, they are the first group of technologies to focus on. Here, there might be some of those unexpected or surprising Wild Card technologies emerge. These may provide additional added value for ForSTI. Regarding the other quadrants, the figure also shows technologies, which are highly attractive/important, but not feasible, meaning that there are not enough resources (e.g. time, skills, funds etc.) to exploit them, and they currently remain under-exploited. Strategies can be developed to make these technologies more feasible through allocation of resources. There are also technologies with low attractiveness/importance and high feasibility (bottom-right corner). Resources used for these technologies can be directed towards the under-exploited technologies to increase their feasibility and eventual exploitation as critical technologies. The bottom left corner consists of technologies, which have both low attractiveness/importance and low feasibility.

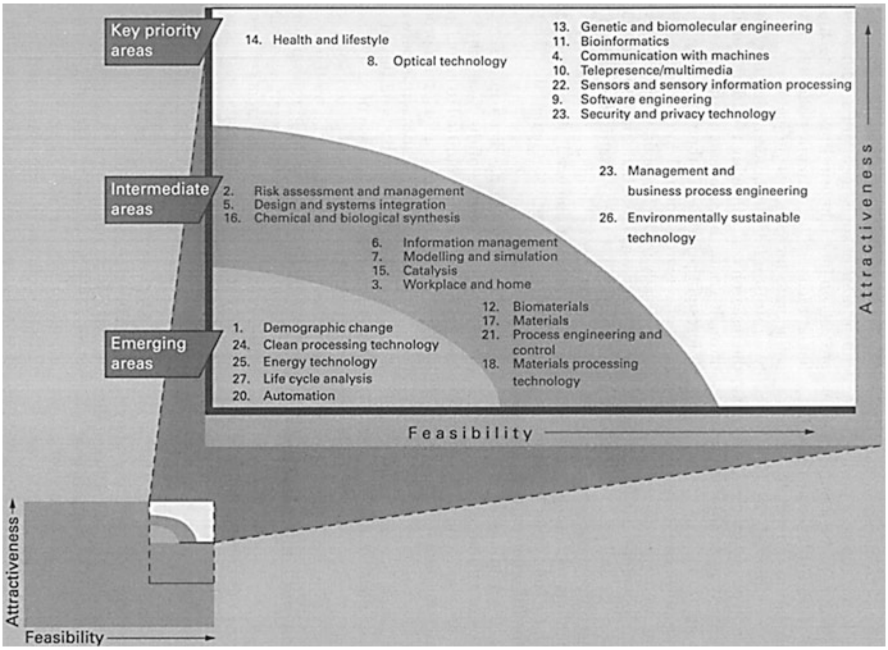

Fig. 9.4 Priority areas in UK Foresight. *Source:* Steering Group of the Technology Foresight Programme (1995)

This may be due to two reasons. On the one hand, these technologies may be considered as low priority technologies and do not require immediate resource allocation. On the other hand, they may be considered as emerging areas, which may require particular attention in case they may become attractive/important in the future such as demographic change and clean processing technologies identified in the first UK ForSTI exercise. In the UK case, the precise way in which attractive and feasibility combinations were achieved remains somewhat obscure, and the results for each of the over 1000 topics considered were not published; but a broad overview of priority technology areas was presented, and this is reproduced in Fig. 9.4.

Prioritisation essentially involves reducing the initial list of technologies to a smaller list representing the critical technologies, as identified by the set of criteria that are being applied. Prioritisation is potentially a controversial activity, creating a pecking order among technologies—and thus some loser. In order to avoid direct lobbying at this stage, the voting process can be split in two parts. At the first stage, experts identify innovative and technology-enabled products and services which are most attractive and feasible for the country. At the second stage, they identify a set of technologies providing most important contribution to the selected products and services.

In surveys such as that described above, a voting procedure is effectively being used to make the selection from the initial list of technologies. It is common for there to be some assessment of attractiveness (impact) and feasibility, though these can be explored at more or less depth. In studies which are mainly Critical Technology exercises (the UK Foresight had a wider remit) this prioritisation process takes centre stage.

Klusacek (2003) describes how this approach was used in the Czech ForSTI exercise. Technologies having a good score for both attractiveness and feasibility are potential candidates for the final list of critical technologies; and these two parameters were calculated from more detailed criteria which respondents applied to technologies from an initial list. The individual criteria included 4 economic benefits (e.g. contribution to GDP, to exports), 5 social benefits (e.g. contribution to health, to security…), 7 environmental benefits (e.g. materials and energy effectiveness…) and 8 research and technology opportunities (e.g. ability of research to produce technologies, possibility of breakthroughs…); feasibility was considered in terms of 5 areas of application potential (e.g. competitiveness of the sector, support in policy and regulations…) and 7 areas of research and technology potential (e.g. level of technology infrastructure, financial requirements…). The individual criteria were ranked on 5 point scales (ranging from 1 (low), to 5 (extremely high) benefits or potential).

More elaborated prioritisation criteria were formulated and used as a part of the Delphi survey designed for the Turkish Vision 2023 exercise (Box 9.1).[8]

Box 9.1: Prioritisation Criteria for Vision 2023

Each topic statement was assessed considering a set of ‘feasibility’ and ‘importance’ criteria (Fig. 9.5).

It should be remembered that the formulation for identifying prioritisation criteria is a part of the ForSTI process. For instance in the case of aforementioned Vision 2023, the criteria were initially identified by the ForSTI Steering Committee. A long list of criteria was generated. Then the list was shortened through first clustering. The final set of criteria illustrated in the figure was determined following a final voting session during a Steering Committee meeting. The process did not end with the final list. Each criterion in the list was given a weight considering that some of them might be more crucial for the selection of critical technologies than the others. These weights were used to generate a feasibility and importance ‘index’ for each technology area. The weights given for the importance index was as follows:

- Competitive strength: 28 %
- S&T and innovation capacity: 26 %
- Environment and energy efficiency: 16 %
- Creation of national value added: 15 %
- Quality of life: 15 %

(continued)

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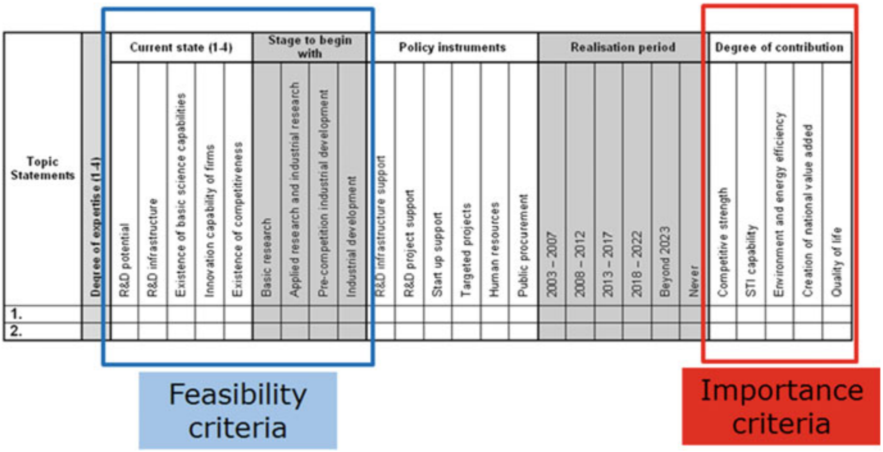
[8] http://www.tubitak.gov.tr/en/about-us/policies/content-vision-2023 (Accessed on 03.11.2015).

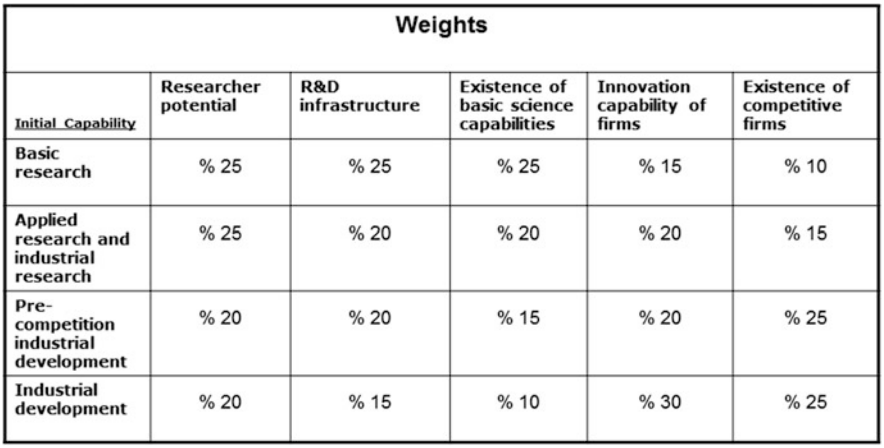
Box 9.1 (continued)

A more complicated algorithm was used for weighting the feasibility criteria to generate feasibility index. Weights were given based on the levels of technological development (including basic research, applied and industrial research, pre-competition industrial development, and industrial development). Below is the matrix produced to illustrate how the feasibility criteria were weighed against the level of development (Fig. 9.6).



Topic Statements	Degree of expertise (1-4)	Current state (1-4)					Stage to begin with				Policy instruments						Realisation period						Degree of contribution				
		R&D potential	R&D infrastructure	Existence of basic science capabilities	Innovation capability of firms	Existence of competitiveness	Basic research	Applied research and industrial research	Pre-competition industrial development	Industrial development	R&D infrastructure support	R&D project support	Start up support	Targeted projects	Human resources	Public procurement	2003 – 2007	2008 – 2012	2013 – 2017	2018 – 2022	Beyond 2023	Never	Competitive strength	STI capability	Environment and energy efficiency	Creation of national value added	Quality of life
1.																											
2.																											

Fig. 9.5 Prioritisation criteria in a Delphi survey: the case of Vision 2023



Weights					
Initial Capability	Researcher potential	R&D infrastructure	Existence of basic science capabilities	Innovation capability of firms	Existence of competitive firms
Basic research	% 25	% 25	% 25	% 15	% 10
Applied research and industrial research	% 25	% 20	% 20	% 20	% 15
Pre-competition industrial development	% 20	% 20	% 15	% 20	% 25
Industrial development	% 20	% 15	% 10	% 30	% 25

Fig. 9.6 Feasibility index used in Vision 2023

Following this example, it should be said that identifying critical technologies through setting priorities can be a complicated, painful and divisive process. Building consensus between the participants of ForSTI through this process plays an important role. We should also underline that likewise in any stage of the process the approaches to the identification of critical technologies and setting priorities should be tailored to match the situation. Once again, one size does not fit all!

The next step would normally be to consider what sorts of policy measure should be recommended to increase the prospects of this opportunity being seized. However, this is most often the task undertaken by the expert panel or core group, and this group may well want to review the results of the survey (or whatever voting approach has been used). For example, it might be that some technologies have been considered only by a few experts, or that there is very substantial difference in viewpoints across different respondents. The expert group, then, will typically generate the final list of technologies as well as elaborate the recommendations of what should be done in respect of these choices. Again, there is a chance that some special interests will be voiced or lobbying take place, so the sponsors and project managers should have a clear explanation of any major changes introduced into the prioritisation at this point (Be aware, too, that the algorithms for combining scores on individual elements could be playing an important role here—for example, economic benefits might be ranked above environmental ones, scientific feasibility above commercial exploitation). Sometimes an additional validation by external (for example international) experts can provide more credibility to the results of the critical technology study.

Box 9.2 outlines highlights of a recent Russian Critical Technologies study.

Box 9.2: Russian Critical Technologies 2020

Among the key instruments of Russian STI policy is *National S&T Priorities and List of Critical Technologies*, a high-level document signed by the President. This is used as a background for selecting projects to be funded in the framework of the National S&T Programme, and in a number of other government STI related programmes. The first list of national critical technologies in Russia was developed in 1996; it has subsequently been revised in 2002 and 2006. The 2006 lists comprised 8 S&T priorities, and 34 critical technologies. Government regulations specify that these documents will be revised regularly, (every 4 years) and work on the revision of critical technologies started in 2010.

The aim was to consider the most important technologies in terms of their potential for bringing practical results within a 10-year horizon; there was a particular focus on technologies that are close to practical implementation. The study was to a large extent based on the results of an earlier performed *national S&T Delphi: 2025* that enabled the assessment of future demand for technology-intensive goods and services.

(continued)

Box 9.2 (continued)

Two main criteria were used for selection of critical technologies:

1. promoting economic growth and enhancing competitiveness of Russia's national economy in both traditional and emerging markets;
2. providing Russia's national security, including its technological security.

The number of critical technologies to be selected for the civil sector was restricted, in order to concentrate resources and provide sufficient budget funding for each of the critical technologies (funds coming from the national S&T programme and other instruments). Each critical technology was to be accompanied with a set of measures for achieving research results and their further implementation.

The methodology involved the following actions:

- developing criteria for creating expert panels for priority areas;
- detailed analysis of critical technologies from the previous list, assessment of their use for developing innovation products, competitiveness in domestic and foreign markets;
- identification of research areas with the greatest potential for developing innovative products and contributing substantially to the economic growth and competitiveness;
- creating revised lists of priorities and critical technologies, together with recommendations on their use,
- evaluating the innovation potential of critical technologies,
- developing proposals concerning practical implementation of the selected S&T priorities.

To achieve this, quantitative and qualitative methods were used, including desk research on promising S&T areas and two expert surveys (involving more than 200 leading Russian scholars). One was aimed at the evaluation of existing S&T priority areas, one asked about the most important prospective innovation products and services, as well as about the technologies that might play a critical role for those innovations. The survey results for each priority area were discussed by leading researchers and industrialists in thematic expert panels.

Each expert was asked to nominate 10–12 important innovation products (or services) in their sphere of interest and work, that would meet the two criteria mentioned above, and that could be produced in Russia, with the help of domestic S&T developments in the forthcoming decade.

The choice of key products was accomplished, initially by. The experts described the main features of each of these products, and identified technologies that need to be developed for their creation. The information on the products thus

(continued)

Box 9.2 (continued)

obtained was systematized, and offered to expert panels for further discussions. During these discussions, the original set of products was revised; major innovation product groups were identified according to the main priorities mentioned above. Sets of the most important innovation products and services that can be produced in Russia in the next 10 years, typically encompassing around 20–30 product groups, were thus generated for each priority area.

In addition, experts in the thematic groups analysed the national system of social and economic goals, as formulated in the *Concept of National Socio-economic Development 2020*, as well as in a number of other major strategic documents of the Russian Federation. Major government bodies, state academies of sciences and the largest state-owned corporations were asked to submit their proposals for revising the national S&T priorities and critical technologies and these proposals were analysed in relevant thematic expert groups.

Having examined the survey results and these discussions, expert panels drew up a list of prospective innovative goods and services involving new technologies. Those technology areas promising most innovative potential were identified, and compiled into revised lists of S&T priorities and critical technologies. These revised lists were approved by the Russian president in July 2011.

Altogether six S&T priorities in the civil sector were formulated, as in the left-hand column of the table below: Nanoindustry; Information and communication technologies; Life sciences; Rational use of nature (efficient use of materials, etc.); Transport and aerospace; and Energy.

The revised list of critical technologies consisted of 26 items, as in the right-hand column. For each of these, a detailed "passport" was prepared. This contained:

- a brief description of the particular technology,
- the subject area,
- the areas of practical application,
- how its level of development in Russia compared to that of the world leaders in the field,
- production capacities, and, finally,
- an assessment of the global and national markets for innovative products and services related to the technology in question.

Priority areas	Critical technologies
Nanoindustry	1. Computer modelling of nanomaterials, nanodevices, nanotechnologies
	2. Nano-, bio-, information, cognitive technologies
	3. Nanomaterials and nanodevices diagnostics
	4. Nanodevices and microsystems
	5. Technologies for manufacturing and processing construction nanomaterials
	6. Technologies for manufacturing and processing functional nanomaterials

(continued)

Box 9.2 (continued)

Priority areas	Critical technologies
Information and communication	7. Technologies providing broadband access to multimedia services
	8. Information, management and navigation systems
	9. Technologies and software for distributed and high-performance computer systems
	10. Technologies for creating component base & energy-efficient lighting devices
Life sciences	11. Bio-catalytic, bio-synthetic and bio-sensor technologies
	12. Biomedical and veterinary technologies
	13. Genome, proteome and post-genome technologies
	14. Cellular technologies
	15. Bioengineering technologies
	16. Technologies to reduce damage from socially significant illnesses
Rational use of nature	17. Technologies for monitoring and forecasting the state of environment, prevention and liquidation of environment pollution
	18. Technologies for exploring, developing and mining natural resource sites
	19. Technologies for prevention and managing consequences of natural and technological emergences
Transport and aerospace	20. High-speed transportation vehicles and intelligent systems for operating and managing new types of vehicles
	21. New-generation rocket and space systems and transportation vehicles
Energy efficiency, energy saving, nuclear power engineering	22. Basic power electrical engineering technologies
	23. Nuclear power engineering, nuclear fuel cycle, safe handling of nuclear waste and depleted nuclear fuel
	24. New and renewable energy sources including hydrogen power engineering
	25. Energy saving systems for energy transfer, distribution and use
	26. Energy-efficient power generation and transformation technologies based on biofuel

9.3.3 Limitations and Potential Weaknesses of the Critical Technologies Approach

The focus on technologies may lead to an overlooking of nontechnology issues (including issues involving "upstream" science and "downstream" innovation processes). This focus on technologies may risk neglecting broader social options—it might be possible, for example, to examine critical areas for social innovation instead or alongside critical technologies. In principle, the approach could be tailored to address issues where technology is not the main focus.

In common with other approaches based on expertise, there is a danger of relying on a relatively narrow group of experts, whereupon there are possibilities of simply reproducing the received wisdom of "the great and the good" (in the English formulation—one which implies a rather restricted elite view), and of being "captured" by a particular industry lobby pressing for its own interests.

9.4 Moving on to Interpretation: Roadmapping

The various methods so far outlined in this chapter are very much oriented towards establishing the options which are able to accomplish most by way of moving toward a desirable future, or to identifying priorities where there are many options to consider.

These methods can be seen as extending the process of Integration that is codified by modelling techniques, moving it on to beginning to create appraisals of more normative futures, often with targets and some basic indicators attached. The ForSTI process at the Intelligence stage develops an understanding of the past and present state-of-the-art of systems. The Imagination phase then develops a set of alternative futures and the Integration phase makes those options explicit and comparable for appraisals. Once the process shifts from the exploratory to a normative stage, the next task is to develop strategies to plan the journey into the desirable future. This is the key function of the Interpretation phase, which moves on yet further from Integration. Probably the most salient method here is the technique of Roadmapping, to which we now turn.

A roadmap is a layout of paths or routes that exist (or could exist) in some particular geographical space. It is used by travellers to decide among alternative routes towards a physical destination. Roadmaps provide essential understanding of proximity, direction and some degree of certainty in travel planning. As a frequently used method within industry, roadmapping has proved to be a useful tool for technology management, strategic and operational decision making and action planning. It is a normative and goal oriented method, where attempts are made to achieve a desired future state of development. The method was originally suggested by Motorola in the beginning of the 1980s, since when it has been used in a wide variety of contexts—particularly in high-tech industries at corporate and sectoral levels.

Galvin (1998) defines roadmap as "*an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of the change*". Roadmaps communicate visions, attract resources from business and government, stimulate investigations and monitor progress. They became the inventory of possibility for a particular field. Although roadmaps are deceptively simple tools in terms of format, their development poses significant challenges. This is because their scope is broad, and generally covers a number of complex conceptual and human interactions (Phaal et al. 2004).

As decision aids, roadmaps are used for (1) portraying structural relationships among science, technology and applications, thus (2) improving coordination of activities and resources in increasingly complex and uncertain environments, (3) identifying, evaluating, and selecting strategic alternatives that can be used to achieve desired S&T objectives, (4) communicating visions to attract resources, (5) stimulating investigations, and (6) monitoring progress.

The major benefits of Roadmaps include:

- Providing a mechanism for translating desirable futures, societal demands or grand challenges to be addressed into future markets, products, services, STI, and eventual research and development activities to be pursued from the present day
- Helping to identify opportunities and gaps in STI programmes
- Allowing a plan for the allocation of resources including time, financial resources and skills
- Enhancing communications among stakeholders such as researchers, STI developers, product manufacturers, service providers, suppliers and users among all the other interested groups
- Providing information to make better STI investment decisions by developing consensus among decision makers
- Creating a multi-disciplinary and cross-functional working environment with the better alignment of decision making in research, industry and policy making

Roadmaps have been used in a number of application areas for a wide variety of purposes, such as product planning, service/capability planning, strategic planning, long-range planning, knowledge and asset planning, programme planning, process planning and integration planning. In recent years roadmapping has become also a very popular tool for ForSTI exercises.

9.4.1 Format and Architecture of Roadmaps

Due to the wide range of application areas, types of roadmaps have varied. Some examples include:

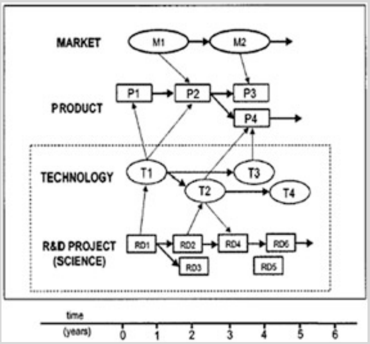
- science/research roadmaps
- cross-industry roadmaps

- industry roadmaps
- technology roadmaps
- product roadmaps
- product-technology roadmaps, and
- project/issue roadmaps

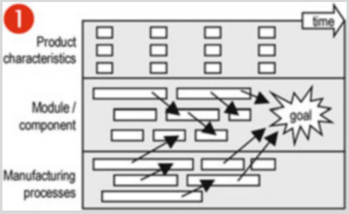
As a result of these diverse application areas roadmaps have been presented in different formats. However, the main elements of roadmaps, which are nodes and links, are always maintained. Box 9.3 presents key elements of roadmaps and various ways of organising roadmaps in different formats, which can be determined according to the purpose and focus of the roadmap.

Box 9.3 Elements and formats of Roadmaps

Elements of a roadmap
A roadmap consists of **nodes (a)** and **links (b)**.
These elements can have quantitative and qualitative attributes.
Construction of a roadmap requires identification of the nodes and their attributes, connection of the nodes with links, and specification of the link attributes.



Formats of roadmaps
Roadmaps can be represented in various formats based on the objectives, use and roadmapping tools.
Typical roadmap formats include:
1. **Multiple layers,**
2. **Bars,**
3. **Network diagrams**
4. **Flow charts**[9]
Besides these formats, roadmaps can be organised as tables, graphs, pictorial representations, a single layer, and texts.



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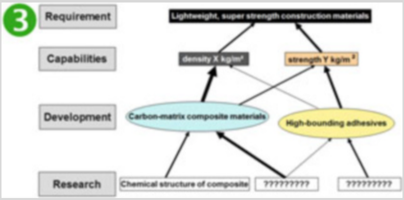
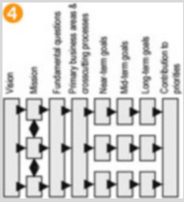
[9] Figures 1, 2 and 4 are based on (Phaal et al. 2001).

Box 9.3 (continued)





Whatever format is used, a generalised architecture can be mentioned for all roadmaps. This architecture typically involves four or five layers, though there are examples of roadmaps with three or more than five layers. All layers may have different attributions based on the objectives, contents and orientations of the roadmaps. For example, the roadmap structure suggested by Phaal (2015) is a market oriented one, which considers a new market or exploiting an existing one by developing businesses, products and services, systems, and science and technology (Fig. 9.7).

Another roadmap presented by Zurcher and Kostoff (1997) involved four layers, labelled as requirements, capabilities, development and research (Fig. 9.3). Different combinations of layers can be used for different roadmaps. Some options are given below, which can be selected and combined in line with the purpose of the roadmap (Table 9.1).

In ForSTI, the process of roadmapping helps to facilitate a structured dialogue. It aids communication, both at the operational, technical and strategic levels, while providing a practical means for ensuring better alignment in the prioritisation and resourcing of STI programmes. The emphasis on the visual and graphical aspects of roadmaps offers several benefits, compressing extensive and complex information into a relatively small space while enabling comprehension of relations over time and across the layers that have been chosen. Thus roadmaps help to check the consistency of ideas from concepts to products and services and STI activities. For instance, they effectively integrate **technology push** with **market pull**.

From an STI planning and assessment perspective, roadmaps are fundamentally visual display aids that crystallise the linkages among the existing or proposed research programmes, development programmes, capability targets, and requirements. As an example, Fig. 9.8 presents a roadmap for “environmentally friendly, non-polluting car”.

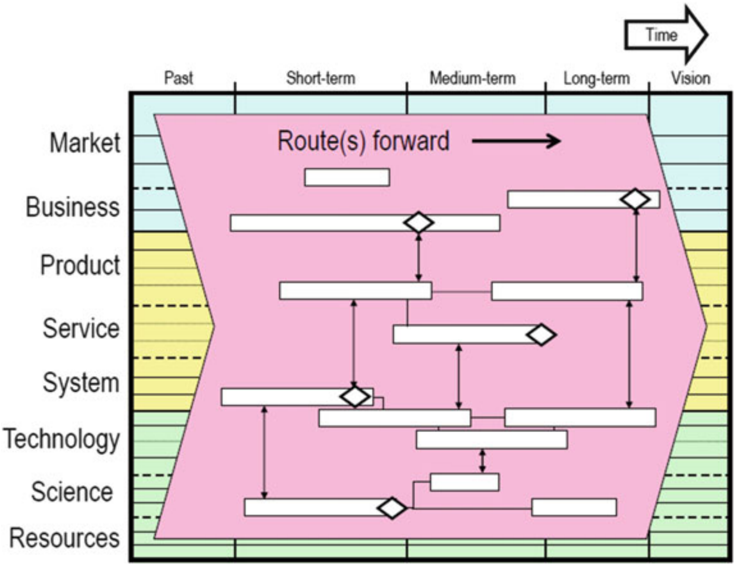


Fig. 9.7 An example roadmap framework (An earlier version of this architecture presented by Phaal (2003) included five layers: Market, Product, Technology, R&D Programmes, as well as Resources at the bottom of the roadmap to indicate capital investment/finance, supply chain and staff/skills requirements across time. This 2015 version of the architecture adds Business, Services, and Systems layers into the roadmap architecture as these have become more and more crucial across time for successful market generation and exploitation.)

Table 9.1 Possible layers for a roadmap architecture

Layers	Labels
Layer 1	Markets, Customers, Competitors, Environment, Industry, Business, Trends, Drivers, Opportunities, Objectives, Visions, Strategy, . . .
Level 2	Products, Services, Applications, Capabilities, Performance, Features, Components, Families, Processes, Systems, Platforms, Requirements, Risks, . . .
Level 3	Technologies, Competencies, Knowledge, . . .
Level 4	Science, Research, Development, . . .
Level 5	Resources, Skills, Partnerships, Infrastructure, Supplier Facilities, Organisation, Standards, Finance, . . .

The top layer of the roadmap illustrates the key requirements for achieving the overall aim: An environmentally friendly non-polluting car should have improved fuel efficiency with reduced CO_2 emissions. These requirements are made explicit with capability levels identified at the second layer. For instance, an improved fuel efficiency requirement will be met if the car reaches the fuel consumption levels of 100 miles-per-gallon. One of the ways of achieving this level of consumption is to develop Fuel Cells, which is indicated in the third layer of the roadmap. Finally, the fourth layer explains that research on electro-chemistry should be conducted to develop fuel cells. The whole

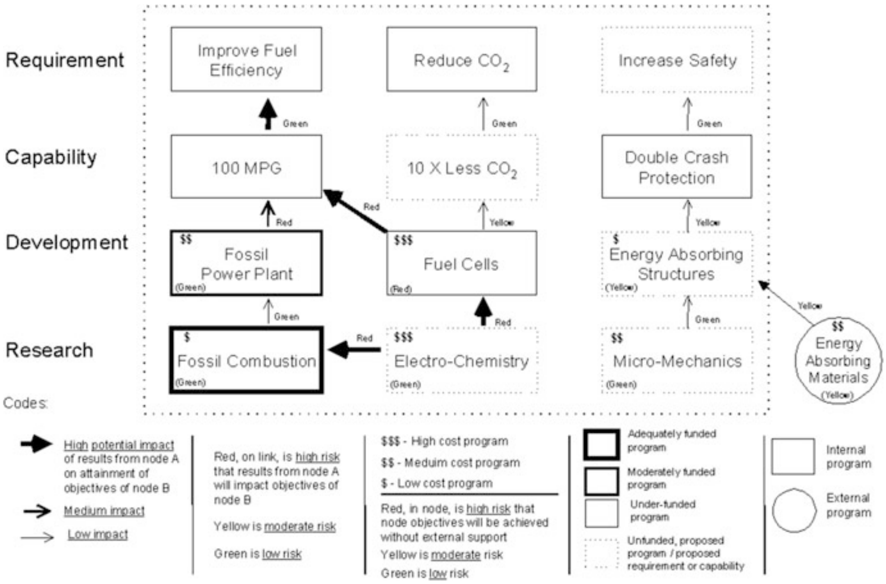


Fig. 9.8 A roadmap for "environmentally friendly, non-polluting car". *Source:* Zurcher and Kostoff (1997)

roadmap can be read and interpreted in this way. The roadmap also illustrates further attributions for its nodes and links. For instance, the thickness of the arrows indicates the impacts of the notes, which may be high, medium or low. This shows the impact of one node on attainment of the objectives of the other one. Similarly, other attributions to indicate the risks, costs and funding increases the power of the roadmaps for communicating as much information as possible on the STI programmes.

It is also important to remember that the context and requirements for STI are liable to changes continually due to some uncertainties being resolved and some new ones emerging, not least in technology applications and STI policy. This may necessitate rethinking or recalibration of timescales, required capabilities, and other targets in STI programmes. Therefore, roadmap processes should ideally have a sufficiently flexible structure to incorporate these dynamic changes.

Roadmaps are produced through a systematic process, typically engaging the participation of knowledgeable stakeholders through workshops. The process can be organised as a stand-alone activity, as well as being a part of a larger overall ForSTI process. We describe the key steps of the roadmapping process in the next section.

9.4.2 The Process of Roadmapping

Roadmapping asks a set of critical questions:

- Where are we now?
- Where do we want to go?

- What are the ways of getting there?
- What should we do from now on?

The answers for the first two questions are given in the earlier phases of the ForSTI activity. The initial scoping and scanning in the Initiation and Intelligence phases helps us to establish where we currently are. The process of Imagination and Integration helps us to explore futures and undertake appraisals, which result in some specification of a desirable future to be aimed at. Then the process of roadmapping explores the ways of achieving the desirable future, the strategies and actions liable to be required.

A fully-fledged roadmapping process consists of two key components. The first one is a workshop with the participation of experts and stakeholders. The second component is data generation and analysis. The two processes go in parallel and support each other. A roadmapping activity may be undertaken in a single workshop in a day up to several months. The amount of resources (time, skills, funding, expertise etc.) devoted for the roadmapping activity will affect the quality and the quantity of the output. However, regardless of the duration and intensity of the activity, a systematic roadmapping process roughly consists of three phases (Fig. 9.9). Although the process is described for Technology Roadmaps, the steps can be considered as generic and can be applied to other types of roadmaps (e.g. policy, strategy, market/product roadmaps).

The planning and preparation phase includes collection of the information for the roadmapping process, ensuring the participation of experts and stakeholders, organising necessary infrastructure such as hardware and software, which may be used to facilitate the roadmapping process. Then, scope and boundaries of the roadmap are defined. The discussions in this preliminary phase of the roadmap are organised around the overall goals, needs and problems identified. As mentioned above, this phase can be informed by other methods. For instance, scenario planning might precede roadmapping for the creation and specification of future

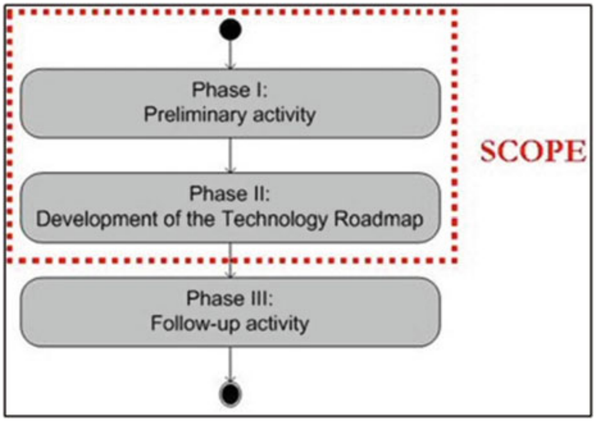


Fig. 9.9 Three phases of the roadmapping process. *Source:* Bray and Garcia (1997)

markets, products and technologies. Saritas and Aylen (2010) discuss ways of integrating scenarios and roadmaps before, during, and after the roadmapping exercise. Saritas and Oner (2004) present ways of integrating the Delphi surveys with roadmaps in the ForSTI process. During the second phase, the focus of the roadmap is defined; this is where what to include in and exclude from the roadmap is discussed. At this stage it is useful to identify measurable capability levels, which will then be used to assess whether the target levels have been achieved. Subsequently, important gaps in market, product and technology intelligence are identified. Alternative products and technologies (for example) are discussed along with their timelines. The type of R&D or similar "upstream" effort liable to be required for obtaining those technologies and products can then be identified. A roadmapping report is produced which should inform—and indeed specify much of—the development of strategic and operational level strategies for securing funding, planning human and other resources and equipments and organising supply chains.

Phaal et al. (2001) suggests four consecutive workshops for the roadmapping process. Following the preliminary phase, the first workshop considers the future markets. First, performance dimensions, and market and business drivers are defined and grouped. Following the prioritisation, Strengths, Weaknesses, Opportunities and Threats (SWOT) are discussed. Then, product, technology and knowledge gaps are identified. The second workshop is more product-oriented. Creation of product feature concepts, grouping, impact ranking and analysing gaps are the main activities of this phase. In the third workshop, technology solutions are produced and grouped. Following an impact ranking, gaps are identified. The final workshop covers the setting of milestones, product and technology charting, resource identification, analysis of gaps and lastly plans on the way forward.

Following the construction of the roadmap, various follow-up steps are taken to critique and validate the roadmap. A roadmap is usually presented with a report, which explains its logic. This report also covers strategies and actions to be taken along with an implementation plan. It needs to be disseminated to relevant parties.

The process does not end with the roadmap itself. A follow-up stage for the implementation, monitoring and revision processes should also be considered as a part of the overall process. This phase begins with the launch of the roadmap and may recur sometime after during the implementation process. Review and evaluation procedures are useful, not only to monitor the progress, but also to update the roadmap and derive lessons for the future roadmapping activities. A recent publication by the International Energy Agency (IEA 2014) provides an example of roadmapping process and guidance on development and implementation of it in the energy technology domain. Box 9.2 presents a case study of a Technology Roadmapping Exercise in the area of Information and Communication Technologies and Systems.

In ForSTI applications, roadmaps ***represent the information obtained throughout the ForSTI process***, and ***present it to a wide range of participants*** to elicit their responses, and obtain their participation for consensus generation on actions. The roadmapping process enables sometimes conflicting and perhaps qualitatively different views, priorities and concerns of the participants to be ***compared***, ***merged*** and ***synthesised*** into a coherent set of outcomes. Roadmaps are then used to (1) provide a mechanism to forecast developments in targeted areas; (2) present a framework to help plan and coordinate (S&T) developments at any level such as within an organisation or company; throughout an entire discipline, industry or cross industry; even at national or international levels; and (3) provide information to help make better informed and targeted decisions.

Because roadmapping is a participative process, it generates not only products like visualisations and reports, but also important process outcomes. During the process, roadmapping ***facilitates a structured dialogue*** and aids ***communication***, which are essential to the ForSTI process. Roadmapping helps to develop consensus among decision makers. Thus, it brings better alignment of organisational decision making. Roadmapping involves multidisciplinary cross-functional working—and this may well be essential for the roadmap to meet its objective of providing common guidance for the whole organisation.

Several critical factors require attention when embarking upon a roadmapping exercise:

1. The pathways between S&T and eventual applications are many; are not necessarily linear or unidirectional; and require significant amounts and types of data
2. Substantial time and efforts are required to portray these links as accurately as possible, and substantial thought is necessary to articulate and portray this massive amount of data
3. Because of the inherent uncertainties in research and development, as well as the continually evolving requirements and capability targets in large programmes, a roadmap should have a sufficiently flexible structure to incorporate these dynamic changes
4. Committed leadership is important because considerable time and effort is involved in the creation of the roadmap. Leaders and sponsors must ensure that the process is completed successfully and produced expected outcomes.
5. Role of the roadmap manager or facilitator and the competence of roadmap participants/team effects the success of the roadmapping process

It should be remembered that incomplete roadmaps only portray a fragmented and isolated picture. To be most effective, roadmapping and other management decision aids need to be fully integrated into strategic planning and operations of the organisation. Starting any major STI initiative requires clear messages for all interested parties, whose activities need to be aligned to a greater or lesser extent.

Box 9.4 presents a case study on Technology Roadmap.

Box 9.4: TECHNOLOGY ROADMAP – Case Study

A roadmapping study for the sector of light emitting diodes (LEDs) commissioned by the Russian Nanotechnology Corporation (RUSNANO) was produced in 2008–2011. It was a part of a wider ForSTI study of the nanotechnology sector development until 2030 which had considered long-term trends, problems and challenges, and identified major factors affecting the sector's development in Russia and in the leading developed countries. RUSNANO, being a corporation established by the government with a mission to support nano-based industries in Russia, planned to use the roadmap for identification of prospective areas in nano-enabled manufacturing industries, assessment of potential domestic and global markets, and building a set of optional "roads" that could connect existing R&D capacities with emerging markets.

The roadmap for the LED innovation-based development was oriented toward identifying key LED market niches where RUSNANO (via investing in proper start-ups and promising companies) could get substantial results in the next 5–10 years.

The study engaged 113 key Russian experts representing research community, LED-producing companies (including multinationals located in Russia), users of LED-based equipment, certification bodies, and regulatory agencies. The experts had to meet rather strict requirements like high citation index, regular participation in top-level scientific and/or professional events, professional status, etc.

The study included the following major stages: (1) analysis and integration of the results of relevant Russian and international studies (foresight reports, analytical materials, research papers, market overviews, etc.); (2) expert survey and interviews; (3) discussions in the roadmapping workshops with engagement of expert panels; (4) integration of expert knowledge and development of the roadmap (analytical report and visual presentation); (5) series of discussions at round tables.

Analysis

At this stage, major types of sources of light, potential application areas and relevant market niches were analysed. LEDs and alternative sources of light were examined with respect to their consumer properties and economic efficiency. Among major market segments there were considered lighting, mobile devices and appliances, large-size displays, signal devices and information signs, transport vehicles, consumer electronics and industrial equipment architectural and aesthetic illumination. For each of this niches key products were analysed vis-à-vis their market prospects.

Expert survey

The survey and interviews covered key Russian experts in relevant areas. The questionnaire included issues that had to be clarified before discussing them at the panels meetings, namely: prospects of particular LED technologies;

(continued)

Box 9.4 (continued)

factors enabling and hampering LED production; research and production capacities available in Russia, et al. More than 20 in-depth interviews with key experts allowed identifying the futures uncertainties (“forks” or bifurcations) to be shown on the roadmap.

Roadmapping workshops

In the series of workshops experts discussed technological and market-related prospects of LEDs. Discussions were based on the information obtained from desk research, survey and interviews. They integrated technology push and market pull approaches and focused on finding consensus between researchers and practitioners (producers and user of LEDs) with respect to future prospects of LED industry in Russia.

Development of the roadmap

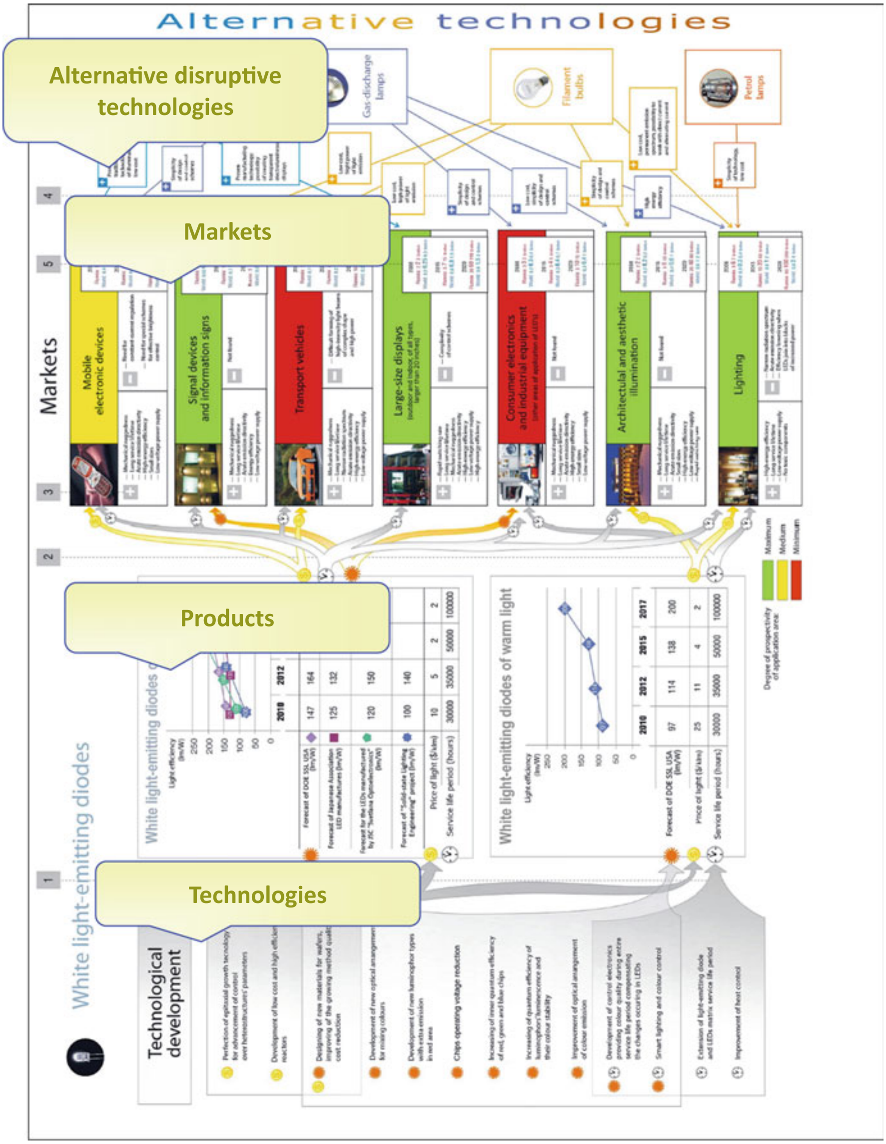
The roadmap was a result of intense discussion in expert panels. It had three parts related to colour LEDs, white LEDs and organic LEDs. Each of them had four layers: (1) technological development describing key technologies and their potential contribution to key characteristics of LED-based products (light efficiency, lm/W; price of light, US$/klm; and service life period, hours); (2) forecasted characteristics of products providing their market competitiveness; (3) market prospects (scenarios and quantitative estimates of national and global markets); and (4) description of alternative technologies which can play a disruptive role in the LED markets.

Roundtables

Two large-scale round tables, with participation of more than 100 experts, industrialists and policy-makers each, were organised to discuss (and validate) the project results. After presentation of the roadmap, the major discussions were devoted to policy measures necessary to support the development of the national LED industry and potential strategies in this sector. A number of proposals have been formulated. A part of them was later implemented. At the second round table, after intense discussions, participants decided to establish a national LED association.

Implementation

The roadmap was used as a background for selection of companies applying to RUSNANO for funding of their activities. Several of them were selected by RUSNANO for investment (they bought up to 49 % of shares for each of them, and later, after the company became profitable, sold the shares). The roadmap was considered as a document both describing the “corridor” of opportunities for RUSNANO investment and providing control figures to monitor the competitive characteristics of companies’ products.



9.5 Conclusions

Following the previous chapter's examination of models, this chapter moved first into the tools for appraisal. Determining what may be a desired future state of the system is often not a straightforward process, since various values and interests are called into play, and numerous uncertainties may be confronted. This may require intensive negotiation between the different stakeholders involved in the process. Future expectations of different stakeholders like research institutions, for- and non-profit organisations, policy makers, and wider society may be fundamentally different from each other. The ForSTI process cannot achieve complete consensus across all these stakeholders. However, the creative and inclusive exchange of ideas and information sharing among participants can help to achieve some measure of agreement as to values, goals, and even targets for the future. Major persisting disagreements can be delineated and debated, although eventually commitments will need to be made towards one or other combination of activities.

Various methods can be used in this process to aid decision making have been described earlier in this book. Multi-Criteria Analysis and Cost/Benefit Analysis (CBA) are among the ones mentioned in this chapter. SWOT analysis can also be mentioned as a useful technique for the purpose of assessment.[10] These methods generally aim at employing a broad range of criteria for prioritisation and selection among alternatives. CBA may attempt to monetise all of these elements, but normative judgements may involve not only economic considerations, but also wide range of social, technological, environmental, political, value/cultural aspects (i.e. STEEPV). Techniques such as ranking, weighing, and scoring of different options can support comparisons across them, and can help clarifying the basis on which priorities can be determined. These ways of prioritising across actions are inherent to Critical/Key Technology approaches, which dominate ForSTI in some settings.

Following the identification of the future priorities, the normative stake of ForSTI begins. Roadmapping is one of the most frequently used tools to portray the route towards the desirable or preferable futures. It has been used extensively in several industries and policy settings, to take into account the fact that actions will need to vary over time as the future unfolds. In recent years, it has become a popular method in national and regional ForSTI exercises, particularly for science and technology policy and planning. Roadmaps produce clear messages the stakeholders and also guides for the synchronisation of different activities. They can be used to monitor progress across time, and can be revised in the cases of faster or slower progress, or when visions or the ways of achieving them have changed.

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[10] See Miles and Keenan (2002) for uses of SWOT in the ForSTI process.