Background paper on Technology Roadmaps (TRMs)

FINAL DRAFT

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Executive Summary

This background paper reports on the use of technology roadmaps (TRMs) related to climate change mitigation and adaptation technologies. The study is motivated by the UNFCCC Conference of the Parties (CoP) request to the Technology Executive Committee (TEC) to catalyse the development and use of TRMs as facilitative tools for action on mitigation and adaptation.

Having originated in industry, TRMs are now used extensively in policy settings too, however their widespread use across sectors and by different stakeholders has resulted in a lack of understanding of their real value to help catalyse cooperation towards technological solutions to the problems presented by climate change. Consequently this background paper presents (i) an overview of different TRM methods, (ii) an initial analysis of gaps and barriers in existing TRMs, and (iii) a review of current TRM good practices.

Approach
The methodological approach taken in the preparation of this background paper follows these three deliverables. Firstly a literature review of academic and industry documents was carried out. Secondly over 150 publicly available TRMs related to climate change technologies were reviewed to determine technological, geographical, time gaps in existing TRMS. Finally, based on the analysis and literature review, quality documents and methods were identified and summarised as good practices.

Main Findings
(i) The literature review revealed there are many TRM methods currently in use, however some fundamental elements are key:

- The roadmapping process is at least as important as the resulting roadmap and visualisation because the process itself has been found to increase communication between essential stakeholders and assists in consensus building.
- TRMs differ fundamentally from scenarios and forecasts, which are descriptive. TRMs are normative in nature, building a desired future state and describing actions and milestones required to reach it.

(ii) The analysis of public domain TRMs revealed the following headline conclusions:

- The set is dominated by mitigation technologies, showing a clear gap in TRMs relating to adaptation technologies.
- The majority of TRMs are produced in Annex-1 countries or by international organisations with very few authored by or targeted at Non-Annex I countries.
- The vast majority of TRMs have a national or international scope.
- TRMs relating to renewable energy technologies are typically more recent than those for other technologies and many of these renewable TRMs set their maximum time horizon to the year 2020.
- Intergovernmental Organisations, Governmental Organisations or Industry author the majority of TRMs, with few from academic or Non-Governmental Organisations.
- Very few of the TRMs analysed could be described as quality TRMs, based on six substantive elements that were identified as important for good practice.

(iii) The last finding highlights the clear need for guidance in order to improve the quality of TRMs. The International Energy Agency's standard TRM format is found to contain many good elements, which are described in the paper. A selection from other TRMs provides additional good examples for specific elements of a TRM and its process.

Recommendations
The following key recommendations, based on the analysed conducted for this background paper, are:

- Guidance and good practice should be disseminated in order to improve the quality and consequent contribution of TRMs to climate change mitigation and adaptation technology development' and transfer.
- The TEC should further explore the perspectives for promoting TRMs for adaptation technologies.
- The TEC should promote the use of TRMs in developing countries; to this end, it could work towards developing cost effective TRM methods and guidance to improve the use of TRMs in and for Non-Annex I countries, and provide training or capacity building on TRMs.
- The role of TRMs in integrating with other existing technology transfer efforts should be further explored by the TEC. This includes Technology Needs Assessments (TNAs) and Technology Action Plans (TAPs), and National adaptation Plans of Action (NAPAs) and Nationally Appropriate Mitigation Actions (NAMAs).

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1. Background

1. The Conference of the Parties (COP), by its decision 1/CP.16, requested the Technology Executive Committee (TEC), as one of its functions, to catalyse the development and use of technology roadmaps or action plans at the international, regional and national levels through cooperation between relevant stakeholders, particularly governments and relevant organizations or bodies, including the development of best practice guidelines as facilitative tools for action on mitigation and adaptation.

2. The COP, by its decision 4/CP.17, adopted the following modalities for the TEC in carrying out the function related to catalyse the development and use of technology road maps or action plans:

(a) Promoting and collaborating with relevant organizations, resources permitting, in organizing workshops and forums to increase the opportunities for sharing experience with experts in developing and implementing technology road maps and action plans as well as other technology-related activities;

(b) Making recommendations on best practices and relevant tools to develop technology road maps and action plans;

(c) Establishing an inventory of technology road maps and action plans;

(d) Making recommendations on concrete actions, such as an international process for the development of technology road maps and action plans as well as support required to enhance the development of these items, and in particular capacity-building programmes that may be appropriate.

3. The TEC, in its rolling workplan for 2012-2013, included preparation of an inventory of existing technology road maps as one of the tasks to be completed by end of 2012 and also review of the inventory of technology road maps to be carried out in 2013.

4. The TEC, at its third meeting held in May 2012 in Bonn, Germany, agreed to prepare a background paper which aims to present an overview of the technology road mapping exercises, an initial analysis on gaps and associated barriers or difficulties, and good practices of technology road mapping exercise.

2. Objective

5. The objective of this background paper on technology road maps for the TEC is to facilitate its consideration on how to further carry out its work on catalyse the development and use of technology roadmaps or action plans at the international, regional and national levels through cooperation between relevant stakeholders, particularly governments and relevant organizations or bodies, including the development of best practice guidelines as facilitative tools for action on mitigation and adaptation . Specific questions are:

- How are TRMs defined, how do they relate to other strategic tools, such as scenarios, forecasts, backcasts, what differences exist between TRMs used at different levels (e.g. corporate, sectorial, (inter)national), and why or when are TRMs needed?
- What Technology Roadmaps (TRMs) do currently exist, what are their key characteristics, and which gaps may be identified?
- What methods and guidelines are available for the development and use of TRMs?
- What can be learnt from good practice examples of TRMs?
- On the basis of this review, what can be recommended for the work of the TEC regarding TRMs?

6. The structure of this paper is as follows. Section 3 presents a definition of TRMs, specific for the TEC context, and why and when a TRM would be needed. Section 4 presents an overview of TRMs related to climate change mitigation and adaptation technologies. Section 5 provides an overview of methods for the development of TRMs. In section 6 we provide a number of good practice examples. Section 7 discusses some specific issues related to TRMs for adaptation technologies. In section 8 we present our key findings. Finally, section 9 contains our suggestions and recommendations regarding the work of the TEC on technology road maps.

3. Defining Technology Roadmaps

7. Technology Roadmaps (TRMs) are used at business and policy levels to support technology strategy development and implementation. While TRMs originated from the private sector, the term TRM is frequently used today in the context of technology research and development as well as in technology policy.

8. The widespread usage of the method means no single definition exists, and common definitions vary considerably (see e.g. Technology Roadmap Network, Phaal et al. 2004, IEA 2009). For the purpose of this study, the following working definition of a TRM is proposed in the TEC context:

> *A Technology Roadmap (TRM) serves as a coherent basis for specific technology development and transfer activities, providing a common (preferably quantifiable) objective, time-specific milestones and a consistent set of concrete actions; developed jointly with relevant stakeholders, who commit to their roles in the TRM implementation.*

9. A TRM bundles three perspectives relevant to the development of a technology. A good TRM deals with:

- Trends and drivers affecting development of applications and technologies
- Applications, products, services and other tangible systems developed in response to trends and drivers, or enabled by technological breakthroughs
- Technologies and other capabilities and resources developed in response to application and market needs

10. A key feature of the TRM method is that the roadmapping process is at least equally important as the resulting roadmap document and structured visualisation. A roadmapping process can increase communication between essential stakeholders for technology development, assist in consensus building, create investors' appetite, and be a basis for future commitment (Garcia and Bray 1997; IEA, 2010).

11. Roadmaps differ fundamentally from scenarios and forecasts, two tools also used in R&D policy. In principle, scenarios and forecasts are descriptive (McDowell and Eames 2006): They explore possible futures without judging whether these futures are desirable or not, assuming that the user of the scenario does not have decisive influence in which scenario will materialise in the end. For example, a company can develop various scenarios for our future energy economy, and then develop a hedging strategy so that it can survive in any of the scenarios. TRMs differ from scenarios and forecasts because they have a normative nature and are more action-oriented: they provide a view of a desirable future, and a pathway with actions towards it. The term 'Scenario' however is probably one of the most versatile terms in policy and strategy contexts. It is sometimes also used in a more normative setting, analysing questions such as 'what will happen if we implement a certain policy'[1].

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[1] For example, in Metz et al. (2007), various regional and national climate change mitigation scenarios are discussed; these provide insights in our future energy economy under active climate policy. Such policies can be an emission cap or other climate mitigation measures and instruments. As such, these scenarios are normative. But also in these applications, scenarios remain less focused on concrete actions and stakeholder engagement than most TRMs are (Metz et al., 2007).

12. TRMs share their normative character as well with visions and backcasting studies (McDowell and Eames 2006). Visions however usually focus only on outlining a desirable future for e.g. a specific technology, not the path towards it. As such, they can serve as a starting point for a TRM. Backcasting studies also start with defining a clear end point, providing a more complete storyline for the future, and subsequently explore possible routes towards it[2]. More than backcasts, but comparable with visions, TRMs often also have an advocacy purpose, and bring key stakeholders together in a shared vision and in a commitment to actions.

13. TRMs are used in corporate settings, but also for sectorial R&D efforts or for governmental policy. A review on TRMs for the renewable energy sector (Amer and Daim 2010) concluded that TRMs differ in their goals and objectives, which they identified as follows. On national level, the prime objective is to aid policy formulation. At sector level, TRMs serve to identify vision, common needs and barriers relevant for the industry, in technical, political and commercial terms. TRMs within an organisation evaluate and prioritise R&D projects to achieve business goals. On all these levels, TRMs seem to have in common that they provide a common ambition, and a basis for action. At corporate level, the TRM can be very exact and binding, as it deals with internal resources over which there is extensive control, and implementation is relatively straightforward. When used for (inter)national policy, TRMs have to deal with more complexity: the innovation system is broader and more complex, resources from various (types of) independent stakeholders need to be aligned, and implementation is more difficult. As a consequence, TRMs for policy usually have an objective that is more broadly defined (sometimes more vague) than in private sector TRMs, and also the required actions are more generic.

14. At corporate level, their purpose is clear when R&D activities need to be prioritised, and activities from various groups within the organisation need to be aligned (Garcia and Bray 1997). At sectorial level, TRMs not only provide alignment to actions of sectorial stakeholders, an inspiring TRM can also be a strong tool for technology advocacy (McDowall and Eames 2006).

15. On national and international level, the policy dimension seems to be leading. In this a context, we identified seven purposes a TRM can have that we consider particularly relevant for the TEC:

1. TRMs can provide a coherent basis for (inter)national technology RD&D policy, setting common objectives, identifying key barriers and milestones, and specifying key actions needed from different types of stakeholders to address barriers and reach milestones.
2. TRMs can be used as a basis for national policy to support the diffusion of climate change mitigation and adaptation technologies
3. TRMs can also be used to catalyse innovations that allow existing technologies to adapt to new markets and settings. Particularly for developing countries, this can be a relevant function, as many technologies are originally with a ‘developed world’ setting in mind.

[2] McDowell and Eames (2006) argue that TRMs usually start from a relatively vague vision, making less explicit assumptions on the future than backcasts do, and focus on barriers and actions to be taken.

4. TRMs can mobilise private and public sector parties' interest in technologies through their participation in the roadmapping process, and can connect them with relevant counterparts in developed countries.
5. TRMs can provide a common platform to mobilise international support. Foreign financial flows for actions like supported NAMAs and NAPAs may be more significant and more effective when they are backed by a roadmap.
6. TRMs can also link to Technology Needs Assessments (TNAs) and Technology Action Plans (TAPs), two relevant approaches under the Technology Mechanism (UNFCCC 2012). While TNAs are executed according to a well-developed structure (see e.g. UNDP 2010), it is still less clear what TAPs should entail, although some tentative structuring is available (Agbemabiese and Painuly 2011). A TRM could provide a structure for transferring the results of a TNA and TAP into action.
7. More broadly, developing countries face the challenge of having to align various technology-related projects from different funders, often working with different ministries within a country. An underlying TRM can serve as a common platform, integrating such projects into a coherent strategy supported by all ministries and donors engaged.

4. Methods used for development and use of technology roadmaps

16. Roadmapping is a flexible method that can support diverse strategic goals, with both the roadmap and roadmapping process adapted to suit the particular context. Time scales, cost pressures, objective and stakeholders all play an important part in shaping the final roadmap. Consequently, there are many different examples of methods used in developing roadmaps. These differences are evident in the TRMs seen in the analysis conducted for this study, which found few consistent elements; even aspects such as clear visions/targets were lacking in almost half of the TRMs reviewed.

17. At a very general level, roadmapping – the process of making roadmaps – has been described as a “disciplined process for identifying the activities and schedules necessary to manage technical (and other) risks and uncertainties associated with solving complex problems.” (Bennett, 2005; in Yan et al., 2011). How this process and management changes, depending on the developer of the roadmap is considered here for two broad categories; first, the private sector and, second, the public sector at the national or international scale.

18. It is important to note that private and public sector TRMs generally have different focuses and aims. Private sector TRMs are primarily focused on R&D - technology development, while public sector TRMs are predominantly concerned with technology diffusion (implementation, deployment). Sometimes public TRMs refer to R&D as well, but quite often the term 'development' is used to denote implementation (or adaptation of specific technologies to local conditions) rather than real, fully-fledged technological innovation. Looking at this from another perspective - private TRMs focus on product innovations (achieving new functionality and performance of technologies), whereas public TRMs focus on organizational innovations (implementing technologies new to a specific field, organization, country etc. to achieve desirable societal, economic and technical outcomes). Table 1 gives further distinctions in terms of process type, technology scope and resources and stakeholder involvement.

Table 1: Private sector versus public sector TRMs

	Private sector TRM	Public sector TRM
Process type	technical task; with focus on specific technology performance parameters, technical project milestones etc.	social process; involving technology diffusion, involvement of multiple parties, adoption/implementation decisions rather than improving technical parameters of specific technologies
Technology scope	focus on one technology type; linked to financial commitments and budgets for in-house development of specific company-controlled technologies and not the broad set of comparable, competing technologies in the market	focused on generic class of technologies; not differentiating between products from various vendors/suppliers
Resources & stakeholders	implemented within the company and can be directly linked to project schedules, with all or most of the necessary resources under the control of corporate planners	stakeholder support needs to be orchestrated

4.1 Private sector TRMs

19. The concept of technology roadmaps originated in the private sector where they have a long history of use in understanding and communicating future relationships between markets, products, and technologies (Lee and Park, 2005). Despite the extensive experience with technology roadmaps in the private sector, there are few comprehensive studies of private sector roadmap development processes or practical guidelines for building technology roadmaps[3].

20. A paper by Sandia National Laboratories, drawn from their own roadmap development experiences, is one of the most commonly cited descriptions of a general process for developing a roadmap in the private sector (Garcia and Bray, 1997). For their proposed process they focus on product technology roadmaps, which are used by many firms, while defining two additional types of roadmaps, an issues-oriented roadmap, and an emerging technology roadmap. Sandia's process is described in three phases — preliminary activity, development of the technology roadmap, and follow-up activity – with a number of self-explanatory steps within each phase (**Error! Reference source not found.**).

Phase I: Preliminary activity
1. Satisfy essential conditions.
2. Provide leadership/sponsorship.
3. Define the scope and boundaries for the technology roadmap.

Phase II. Development of the Technology Roadmap
1. Identify the "product" that will be the focus of the roadmap.
2. Identify the critical system requirements and their targets.
3. Specify the major technology areas.
4. Specify the technology drivers and their targets.
5. Identify technology alternatives and their time lines.
6. Recommend the technology alternatives that should be pursued.
7. Create the technology roadmap report.

Phase III. Follow-up activity
1. Critique and validate the roadmap.
2. Develop an implementation plan.
3. Review and update.

Figure 1: The three phases in the private sector technology roadmapping process
(source: Garcia and Bray, 1997)

21. Garcia and Bray (1997) also stress the importance of involving the right mix of participants in the process, including some that understand the roadmapping process itself, and some that can identify needs, technology drivers and technology alternatives

3 There are a number of case studies available which can offer observations of process and methods, but these are for individual firm and relate their own experiences in developing a roadmap and, therefore, generally don't provide general guidance or practical help (Lee and Park, 2005; Lee et al., 2007).

and paths. They also note that interpersonal skills are a key criterion for a successful process. Finally, they recognise that in some instances experience with roadmaps and/or team exercises may be missing and a roadmapping consultant or facilitator can be used to provide process guidance and assistance.

22. In terms of using the created technology roadmap, a number of steps that relate to use are built into the process, including the development of an implementation plan, as well as the subsequent monitoring of progress and objectives in order to regularly update the roadmap. The idea that technology roadmaps are ‘living documents’ that require regular revision is a common theme across the literature, although the analysis performed in section 4 shows that many technology roadmaps lack an update plan.

23. The above, along with other relevant case studies, can provide a strong starting point for developing a technology roadmap in the private sector. However, it is important to reiterate that the roadmapping process is tailored to the specific needs of an individual firm. The must be sufficient flexibility to customise the process to the specific objectives and organizational context (Lee and Park, 2005; Yan et al., 2011).

4.2 National and international TRMs

24. Although TRMs were originally an instrument used in the private sector, they have increasingly been used as a tool by governments and industry bodies over the last decade to assist in structuring technology and innovation policy or create a common understanding of sectorial goals. In this context, TRMs must typically consider longer timeframes, as well as social and political aspects in addition to those technical aspects more commonly associated with technology roadmapping (McDowall, 2012).

25. Furthermore, the need to build consensus for roadmaps at the national or international level, means that they are almost always collaborative, or at least consultative, in an effort to account for the views as many different stakeholders as possible (McDowall, 2012). This participation of stakeholders is vital in order to improve the chance that target-users of the roadmap will agree on its outcomes and work towards its implementation (IEA, 2010).

26. The IEA (2010) describe a general roadmapping process that focuses on the need for common targets and includes concrete actions. The process includes two types of activities and four phases. The activities are i) expert judgement and consensus, and ii) data and analysis. The four phases, illustrated in Figure 2, are i) planning and preparation, ii) visioning, iii) roadmap development, iv) implementation and revision. The IEA suggest organisations allow 6 to 14 months to successfully develop a roadmap in this context.

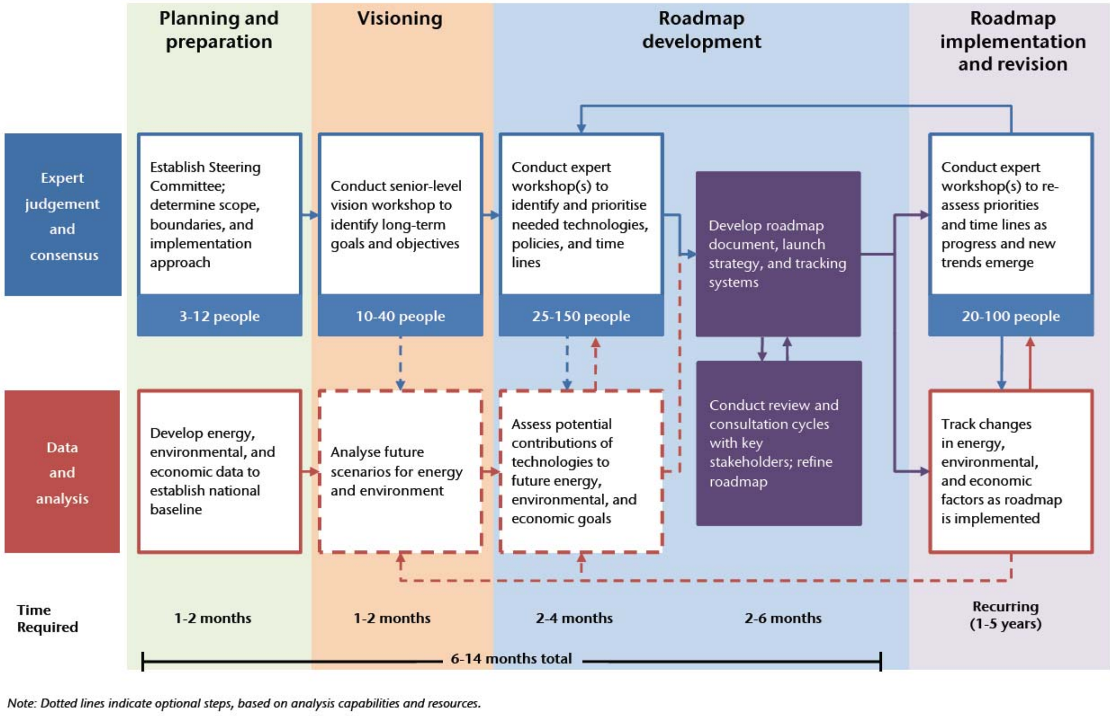


Figure 2: National or international roadmap process, described for energy technologies *(source: IEA, 2010)*

27. The IEA (2010) guide suggests that, "expert workshops and consensus-building activities form the core of an effective technology roadmapping process". They go on to define the work to include target setting, identifying technology needs and assigning actions. This should be conducted by experts that represent not only the different stakeholders, but also the different disciplines that relate to technology development, including technical experts, policy, economics, finance and social sciences.

28. The second type of activity, data and analysis, is used to provide a strong, more quantitative basis for decision-making and to inform the expert workshops. Figure 2 shows a number of optional steps depending on how readily the technology and available data lend themselves to further analysis, as well as the needs of the expert groups.

29. Similar to the roadmapping process described for the private sector, the final phase of national or international roadmapping involves launching the roadmap and communicating it to the target audience. This should be followed by monitoring progress and objectives in order to regularly update the roadmap.

30. As with TRMs in the private sector, roadmapping at the national or international levels should be seen as an on-going and iterative process that involves monitoring and updating as necessary. Ideally, some form of roadmap implementation body – often the same working group or steering committee that was involved in the roadmapping process – monitors progress and actions of stakeholders. Given the large scope of many high-level roadmaps, these responsibilities may also be given to a number of more focussed stakeholder groups, as is done in the IEA technology roadmaps (IEA, 2010).

31. International roadmapping is more likely to require new governance structures to be formed, for example new international committees or associations, while in many instances it may be possible for government agencies or domestic industry associations to convene national roadmapping exercises.

4.3 Improving technology roadmaps

32. One of the key challenges with TRMs is to successfully communicate their usefulness to users. A lack of awareness by users of the usefulness of a certain TRM is often the cause for it not being followed (Yi et al., 2009 in Lee et al., 2012).

33. Lee et al. (2012) show that perceived TRM credibility – i.e. do users feel that it is useful and appropriate – affects TRM utilization. This has important repercussions for the way in which those working in a roadmapping process communicate with the eventual users of a TRM. Strong communication between these two groups will generally improve the credibility of a TRM and therefore the likelihood of successful implementation. Those findings, from research in the context of private sector roadmapping activities, are still relevant and provide valuable lessons on the need to improve communication and interaction between national or international roadmapping teams and domestic or international private sector actors respectively.

Table 2: Summary table of criteria for transition roadmap evaluation
(source: McDowall, 2012)

Criteria	Key questions
Credibility	Is the roadmap based on sound analysis?
	Does the roadmap draw on the right breadth of expertise?
	Has the roadmap secured the participation and commitment of key actors in the innovation system?
	Does the roadmap adequately address the political, social and economic aspects of the transition?
Desirability	Does the transition meet social goals established through democratic institutions?
	Does the roadmap give a clear account of the justification for the proposed pathway, with transparency in aims, process and who took part?
	Is the roadmap process inclusive and participatory?
Utility	Does the roadmap effectively articulate a path forwards that can enable alignment around common goals?
	Is the roadmapping approach appropriate for the stage of innovation system maturity?
Adaptability	Does the roadmapping process involve periodic reviews, updates and learning?
	Is the roadmapping process embedded in a broader institutional structure that enables reflexivity and learning?

34. On a related note, it is important that roadmapping teams strike the right balance for how narrowly a TRM is defined. On the one hand, more prescriptive TRMs have been shown to be most effective in driving action, yet they tend to reflect dominant stakeholder interests and neglect alternative futures. On the other, less narrow TRM outcomes run the risk of inaction from users due to uncertainty. This is particularly

relevant when considering major socio-technical systems changes, or technological transitions. In these instances the most appropriate view of the future or timing for such a transition may not be particularly clear. McDowall (2012) proposes a set of criteria to address how roadmapping for technology transitions can balance these objectives (Table 2).

35. In particular, McDowall (2012) notes that for technology transitions it is important to foster common expectations of the future amongst stakeholders that are conducive to the development of a new socio-technical system. For this reason, TRM processes that consider technology transitions should be transparent, as well as an inclusive participation process that involves open debate on the direction of socio-technical change.

5. Technology Roadmap Analysis

36. This section sets out the analysis of existing technology roadmaps related to climate change adaptation and mitigation technologies. The process of sourcing, filtering and analysing relevant TRMs is described (5.1 and 5.2), before the results of the analysis are presented in a selection of tables and matrices (5.3). Section 5.4 contains our main findings. A full set of all TRMs reviewed, an overview table with all information, and the full matrices and tables produced in the analysis are available in Annexes 1, 2 and 3 respectively.

5.1 Sourcing and Filtering TRMs

37. The development of TRMs has been increasing for a number of years, and there are now many TRMs available in the public domain. These TRMs range from industry TRMs to technology specific TRMs in a wide variety of sectors and by various types of authors. In order to meet the needs of this review, TRMs were selected based on the following criteria:

1. They are available in the public domain
2. They deal with one or more climate change mitigation and/or adaptation technologies as interpreted under the UNFCCC
3. They aim at technology development, transfer and/or implementation
4. They show engagement of public and/or private stakeholders
5. They have some methodological foundations
6. They were published in English language

38. For this review, we attempted to include TRMs from as many different authors as possible. We collected TRMs through different sources:

- The UNFCCC secretariat and several members of the TEC Task Force on TRMs gathered slightly over 120 TRM documents and references to them
- Cambridge University has a TRM database of over 2000 entries, from which we selected TRMs that met the six criteria above (~40 TRMs)
- Some additional TRMs were added because they were known to the consultants (~20)

39. This process, in which we only tentatively checked the information on the selection criteria above, resulted in a set of 192 TRM entries, collected in an Excel database (see Annex 1).

40. In the next round of analysis, we checked more closely whether the documents met the selection criteria, which caused 33 entries to be excluded:

- 6 appeared not to be available in the public domain,
- 1 was not on climate technologies,
- 9 did not aim at technology development, transfer and/or implementation
- 13 did not show any engagement of stakeholders,
- 4 entries appeared double in the list.

41. After this pruning process, we finally ended up with a set of 159 TRMs documents for analysis.

5.2 Classification

42. The following section summarises the key findings from the analysis. One of the aims of this analysis is to identify gaps in existing TRMs. These gaps can be geographical, technological, and time based. Each of the 159 TRMs was analysed in detail to extract information relating to a set of characteristics, in order to enable us to identify these gaps in different dimensions. The following characteristics were extracted from each TRM:

- Technologies
  - The Standard IPCC list of climate related technologies (A-G), in which the energy sector technologies (A) and adaptation technologies were subdivided up to the third level of this classification (e.g. category A.1.2)
  - The other sectors were expanded to their second level (e.g. B.3)
- Geographical source of TRM Author, divided into
  - International
  - Annex I Country
  - Non-Annex I Country
- Geographical coverage of the TRM
  - International Coverage
  - Region Specific (e.g. European, African)
  - Nation Specific
  - Locally Specific (within a nation, e.g. North West USA)
- Year of publication
- Maximum Time Horizon of the TRM, divided into
  - Up to 2018
  - From 2018 to 2022
  - From 2022 to 2031
  - Past 2032
- Authoring Organisation
  - Intergovernmental Organisation (IGO)
  - Governmental Organisation (GO)
  - Non-Governmental Organisation (NGO)
  - Academic
  - Industry
- Substantive elements

  As outlined in Section 3, there are some key elements to a TRM. Each of the TRMs reviewed was checked for the presence of six substantive elements. These were:

  - Process Description

    Is the roadmapping process and methodology described in enough detail to be sure of the roadmaps validity and reliability?

  - Stakeholders Specified

    Are the stakeholders (participants in workshops, experts consulted etc.) specified explicitly?

  - Quantifiable Targets

    Are targets quantified and developed in a vision, and are they measurable?

  - Actions Assigned

    Are actions assigned to specific individuals or organisations?

- Visual Representation
  Does the TRM contain a visual representation containing the three TRM perspectives (see Section 3) along a timeline?
  - Perspective 1 – Trends and drivers affecting development of applications and technologies
  - Perspective 2 – Applications, products, services and other tangible systems developed in response to trends and drivers, or enabled by technological breakthroughs
  - Perspective 3 – Technologies and other capabilities and resources developed in response to application and market needs
- Plan for Update

  Does the TRM set out a plan for a future update, or show any evidence of being updated?

5.3 TRM distribution

Table 3 shows the distribution of the 159 TRMs.

Table 3: Distribution of the 159 TRMs over the various geographical, author and time horizon categories.

	International	Regional	National	Local
Geographical Coverage	41	25	84	9

	International	Annex I	Non Annex I
Geographical Source	28	118	13

	IGO	GO	Academia	NGO	Industry
Author	36	48	11	4	58

	<2018	2018-2022	2023-2032	>2032	Unspecified
Time Horizon	19	32	23	43	43

5.4 Findings of the TRM analysis

43. The following section summarises the key findings by presenting key matrices to demonstrate the gaps identified in this study. The first matrix summarises the number of TRMs analysed referring to each technology. Subsequent matrices deepen the analysis by presenting the TRM's technologies against the characteristics as described in Section 5.2. Grey scale colours are used to indicate relative densities between cells. Darker shades of grey indicate more populated sections of the matrices.

44. It should be noted at this stage that the numbers in the matrices refer to the amount of TRMs that mention a technology, not to unique TRMs. For example, the numbers in the main technology categories (such as A1) are not by definition equal to the sum of the numbers for the underlying subgroups (A11, A12, etc.). This is because some TRMs deal with an entire cluster of technologies (such as Renewables as a whole), and are therefore only categorized as an A1 TRM. Other TRMs provide detailed information about several technologies, and are therefore counted for each of

these technologies, but these documents count only as one TRM in the aggregated group. Full details of the analysis are included in Annexes 2 and 3.

Technologies

45. Table 4 shows the technologies found in the TRM documents reviewed. The main finding from this table is that the TRMs analysed in this study are clearly dominated by mitigation technology TRMs.

To a less clear extent, a number of other findings can be distilled from Table 4. First, TRMs dealing with adaptation technologies (G) are comparatively under-represented. Second, within renewable energy technologies (A1), three technologies dominate: wind, biomass and solar-PV. Third, of all the other energy technologies (A2), hydrogen and CCS, and to a lesser extent nuclear and smart grids, feature strongly. Fourth, within transport technologies (B), alternative fuels (including biofuels, electricity and hydrogen) are most represented. Fifth, there are few TRMs related to energy efficiency technologies outside from HVAC, BES and Transport technologies (C). Finally, in the industrial sector (D), we did find some TRMs Iron and steel (D1), Chemicals (D2), and Cement (D7), but hardly any for other industrial sectors. Agricultural (E), waste (F) and geoengineering (H) TRMs were also scarce.

Table 4: Overview of technologies found in the TRM documents reviewed

Technology	
A1. Renewable energy technologies	55
A1.1. hydroelectricity	5
A1.2. wind energy	15
A1.3. biomass and bioenergy	21
A1.4. geothermal energy	8
A1.5. solar thermal electric energy	10
A1.6. solar photovoltaic energy	18
A1.7. solar heating and cooling	5
A1.8. marine energy (ocean, wave, tidal)	10
A2. Other energy-related technologies	64
A2.1. technologies supporting fuel switching from coal to gas	4
A2.2. use of hydrogen as a fuel	14
A2.3. advanced nuclear energy	11
A2.4. clean coal technologies	5
A2.5 combined heat and power (CHP)	3
A2.6. carbon capture and storage (CCS)	21
A2.7. energy storage and distribution (including smart grids)	12
A2.8. decentralized (distributed) energy systems (DES)	4
B. TRANSPORTATION	35
B1. improving drive train efficiency	5
B2. supporting the use of alternative fuels	23
B3. optimize transport operations	2
C. RESIDENTIAL AND COMMERCIAL BUILDINGS	16
C1. heating, ventilation and air conditioning systems (HVAC)	6
C2. building energy management systems (BEMS)	4
C3. high-efficiency electric lighting	5
D. INDUSTRY	14
D1. iron, steel and non-ferrous metals	5
D2. chemicals and fertilizers	5
D3. petroleum refining	1
D4. minerals	
D5. pulp and paper	1
D6. food industry	
D7. cement industry	3
E. AGRICULTURE	
E1. technologies for agriculture	3
F. WASTE MANAGEMENT	
F1. technologies for waste management	1
G. ADAPTATION	11
G1.1 Coastal zones	1
G1.2 Water resources	8
G1.3 Agriculture	
G1.4 Public Health	1
G1.5 Infrastructure	
H. GEOENGINEERING	
H1. geoengineering technologies	1
Total	436

Geographical Source

46. Matrix 1 (full details see Annex 3) breaks down the previous findings by adding an additional dimension to the analysis. The matrix shows the number of TRMs analysed in each technology along with where geographically the TRM was authored.

47. The main finding here is that the vast majority of TRMs are produced from Annex I countries (339 out of 436 mentions), and to a lesser extent from international authors such as IEA, UN bodies and the Major Economies Forum (MEF) (70 out of 436 mentions). Only a handful of Non-Annex I countries feature, and these focus particularly on water technologies.

Summary of Matrix 1 - Geographical Source (full details see Annex 3)

Matrix 1 Summary	Geographical Source			
	International	Annex I	Non Annex I	Total
A1. Renewable Energy	12	39	4	55
A2. Other Energy	6	53	5	64
B. Transportation	6	29		35
C. Buildings	3	13		16
D. Industry	2	12		14
E. Agriculture		2	1	3
F. Waste Management		1		1
G. Adaptation	1	5	5	11
H. Geoengineering		1		1
Total	70	339	27	436

Geographical Scope

48. Matrix 2 identifies the geographical scope of the TRMs analysed against each technology. Scope in this context refers to the geographical area to which the TRM's contents refer.

49. For the TRMs analysed in this review, the main finding is that the majority (55%) have a national scope, across all technology categories. A smaller group have an international scope, while the limited number of regional TRMs is mostly EU specific.

50. Where the TRMs have national scope, the majority of the TRMs (30) refer to US, as shown in Table 5. The UK (12), Canada (8), and Australia (7) also feature strongly. This may be caused by our selection criterion of the TRMs being available in the English language.

Summary of Matrix 2 – Geographical Scope (full details see Annex 3).

Matrix 2 Summary	Geographical Scope				
	International	Regional	National	Local	Total
A1. Renewable Energy	15	11	27	3	56
A2. Other Energy	13	10	38	4	65
B. Transportation	7	10	16	2	35
C. Buildings	3	1	10	2	16
D. Industry	3	2	8	1	14
E. Agriculture		1	2		3
F. Waste Management		1			1
G. Adaptation	2		9		11
H. Geoengineering			1		1
Total	98	91	219	32	440

Table 5: Geographical Scope Details

Regions		**TRMs**
	Australasia	1
	EU	23
	EU & N-Africa	1
Countries		
	Australia	7
	Bangladesh	1
	Cambodia	1
	Canada	8
	China	1
	Finland	1
	Hungary	1
	Iceland	1
	India	1
	Ireland	6
	Japan	5
	Netherlands	1
	Pakistan	1
	Philippines	1
	Poland	1
	Romania	1
	Spain	1
	Tonga	1
	UK	12
	USA	30
	Vietnam	2

Publication Year

51. Matrix 3 identifies the year in which each of the TRMs was published for every technology category.

52. The main findings from this analysis are that on average Renewable TRMs (A1) are more recent than other energy TRMs (A2). The latter show a relatively constant stream of publications since 2002, while the number of A1 TRMs has grown over the last decade.

53. Two patterns relating to specific technologies are also clear. First, the largest number of TRMs related to hydrogen was published in 2009. Second, there is recent trend in TRMs published in CCS technologies. This may relate to peaks in general attention to these technologies: hydrogen for example experienced quite strong public attention during the late ‘00s, which toned down relatively in later years.

54. Due to the lack of TRMs in other technologies, the identification of any meaningful patterns was impossible.

Summary of Matrix 3 – Publication Year (full details see Annex 3).

Matrix 3 Summary	**TRM Publication Year**													
	0	1	2	3	4	5	6	7	8	9	0	1	2	–
A1. Renewable energy				3		2	3	3	5	14	10	10	7	57
A1.1. hydroelectricity								2	1		1	1		5
A1.2. wind energy						1	2	2	2	4	1	4		16
A1.3. biomass and bioenergy				1		2		2	1	2	5	4	4	21
A1.4. geothermal energy						1		2	2			3	1	9
A1.5. solar thermal electric energy				1				2	1	3		3		10
A1.6. solar photovoltaic energy				1		1		2	2	6	1	4	1	18
A1.7. solar heating and cooling								1	1	1		1	1	5
A1.8. marine energy (ocean, wave, tidal)								1	2	2	3	2		10
A2. Other energy-related	3	1	2	3	1	6	5	3	5	14	8	7	6	64
A2.1. technologies supporting fuel switching from coal to gas	1					1	1					1		4
A2.2. use of hydrogen as a fuel			1	3		3			2	4	1			14
A2.3. advanced nuclear energy		1	1			3		1	1	3		1		11
A2.4. clean coal technologies									1	3				4
A2.5 combined heat and power (CHP)	1				1							1		3
A2.6. carbon capture and storage (CCS)	1					1	1	1		6	4	4	4	22
A2.7. energy storage and distribution (including smart grids)				1		1	1			2	3	2	2	12
A2.8. decentralized (distributed) energy systems (DES)				1	1		1	1						4
Full table in Annex 3														

Time Horizon

55. Matrix 4 denotes the maximum time horizon used in each TRM for every technology category.

56. The majority of renewable energy TRMs uses time horizons that either end between 2018-2022 (15 of 43), or extend beyond 2033 (18 of 43). The two most

common specific time horizons are 2020, which may be explained by the EU policy objectives for that year, and 2050, which coincides with an often-used reference year in many climate scenarios and projections. Of the other energy technologies, the time horizon is more evenly distributed.

57. TRMs related to transport, industry, and adaptation on average feature shorter time horizons.

Summary of Matrix 4 – Time Horizon (full details see Annex 3).

Matrix 4 Summary	Time Horizon				
	<2018	2018-2022	2023-2032	2033-2050+	To-tal
A1. Renewable Energy	3	15	7	18	43
A2. Other Energy	6	12	13	17	48
B. Transportation	7	7	4	7	25
C. Buildings		5	2	4	11
D. Industry	4	4		4	12
E. Agriculture	1	1		1	3
F. Waste Management		1			1
G. Adaptation	4	2	1	1	8
H. Geoengineering				1	1
Total	47	126	45	116	334

Authoring Organisation

58. In authorships of TRMs, there is a strong dominance of Intergovernmental Organisations (IGOs), Governmental Organisations (GOs), and Industry over Non-Governmental Organisations (NGOs) and Academia.

59. IGOs are relatively more active in renewable technologies (A1) than in other energy technologies (A2).

Summary of Matrix 5 – Authoring Organisation (full details see Annex 3)

Technology	Authoring Organisation					
	IGO	GO	Academic	NGO	Industry	Total
A1. Renewable energy technologies	16	18	4	2	16	40
A1.1. hydroelectricity	3	1			1	2
A1.2. wind energy	6	6			3	9
A1.3. biomass and bioenergy	7	7	1	1	5	14
A1.4. geothermal energy	4	4			1	5
A1.5. solar thermal electric energy	6	2			1	3
A1.6. solar photovoltaic energy	6	6		1	6	13
A1.7. solar heating and cooling	5					0
A1.8. marine energy (ocean, wave, tidal)	3	4	2		1	7
A2. Other energy-related technologies	10	25	5	1	23	54
A2.1. technologies supporting fuel switching from coal to gas		2			2	4
A2.2. use of hydrogen as a fuel	1	5	1		6	12
A2.3. advanced nuclear energy	2	5	1		2	8
A2.4. clean coal technologies	1	1	1		1	3
A2.5 combined heat and power (CHP)		1			2	3
A2.6. carbon capture and storage (CCS)	5	9	1	1	5	16
A2.7. energy storage and distribution (including smart grids)	3	3			6	9
A2.8. decentralized (distributed) energy systems (DES)		2			2	4
B. TRANSPORTATION	8	16	1	1	8	26
C. RESIDENTIAL AND COMMERCIAL BUILDINGS	2	5	2	1	5	13
D. INDUSTRY	3	3		1	6	10
E. AGRICULTURE	1			1	1	2
F. WASTE MANAGEMENT				1		1
G. ADAPTATION	3	3	1	1	3	8
H. GEOENGINEERING					1	1
Total	114	147	22	15	132	316

Quality Elements

60. Matrix 6 indicates how many TRMs meet the six substantive elements we defined in Section 4.2: the presence of a process description, a specification of stakeholders, clear (quantitative) targets, clear actions, a structured visual and a plan for updating of the TRM. The main finding resulting from the analysis of quality elements is that the majority of TRMs do not satisfy several of these elements, and very few meet 5 or more of them.

61. Even in the best performing categories (see Annex 3), clear visions, targets and actions are missing in almost half of the TRMs analysed. The other elements, process description, stakeholders specification, and visual representation, appear even less frequently. The least-present element is a plan for updating the TRM.

Matrix 6 – TRM Substantive elements (full details see Annex 3)

Technology	**Substantive Elements**					
	Process	**Stakeholders**	**Targets**	**Actions**	**Visual**	**Update**
All TRMs	**32%**	**36%**	**60%**	**54%**	**40%**	**9%**
A1. Renewable Energy	23%	14%	61%	55%	43%	9%
A2. Other Energy	31%	40%	55%	46%	45%	6%
B. Transportation	37%	49%	66%	51%	31%	9%
C. Buildings	44%	56%	44%	38%	56%	0%
D. Industry	64%	64%	71%	64%	57%	7%
E. Agriculture	100%	67%	0%	33%	33%	0%
F. Waste Management	100%	100%	0%	0%	0%	0%
G. Adaptation	36%	55%	82%	55%	9%	27%
H. Geoengineering	100%	100%	0%	0%	0%	0%

5.5 Key findings

62. The key findings of our TRM analysis are:

- The set is dominated by mitigation technologies; there exists a clear gap in adaptation technology TRMs in the set analysed
- Most TRMs are produced in Annex-1 countries or by international organisations. There is a clear lack of TRMs authored or relevant to Non-Annex I countries.
- Most TRMs have a national scope, TRMs with an international scope having the second-largest share. TRMs for the USA, UK, Canada and Australia are most present in our analysis, possibly because we limited ourselves to TRMs in the English language.
- TRMs on renewable energy technologies are on average more recent than those for other technologies. Many of the renewables TRMs have a 2020 horizon.
- Authors of the TRMs reviewed are mainly Intergovernmental Organisations, Governmental Organisations and Industry.
- Of the six substantive elements we identified as important for a TRM, hardly any TRM included all of them, and none of these elements was present in 50% or more of all TRMs reviewed.

63. The latter finding implies that there is a clear need for guidance on the production of good quality TRMs, even when the guidelines and methodologies discussed in Section 4 are publicly available. Therefore, Section 6 goes into a number of good practice examples, both related to climate change technologies and elsewhere.

6. Good practice guidance

64. This section describes a selection of good practices in order to strengthen the understanding of technology roadmaps, and provide a basis for improving TRM practices. To this end, we selected a representative set of TRMs from our 159-document set in terms of types of technologies, developer, time frame and geographical coverage of the roadmap; see Table 6. Additionally, we have analysed two TRMs on technologies not related to climate change that provide useful good practice examples. Annex 4 provides short summaries of the objectives, methodology and structure of these TRMs.

65. It should be noted, however, that we did not find any ‘perfect’ TRMs in our review. None of the TRMs, for example, covers all six substantive elements we defined in Section 5.

Table 6: Overview of good practice TRMs in this section

		Technology									Geographical Scope					Time Horizon				Authoring Organisation					Substantive Elements					
Climate Change Mitigation or Adaptation Technology TRMs	Unique TRM ID	Renewable	Other Energy	Transport	Building	Industry	Agriculture	Waste	Adaptation	Geo-Engineering	International	Continental	National	Regional	Corporate	<2018	2018-2022	2023-2032	>2032	IGO	GO	Academia	NGO	Industry	Process	Stakeholders	Targets	Actions	Visual	Update Plan
Energy efficiency - Bonneville Power Admin	9		x		x	x								x			x				x					x			x	
Wind energy - IEA	42	x									x								x	x							x	x		
TRM for PV - PV Group	59	x											x				x							x	x					
Electric vehicles roadmap - SEAI	61			x									x						x		x						x	x		
Development and Deployment - Fuel Cells UK	109		x	x									x															x		
Green Chemical Technology - Crystal Faraday	179					x							x					x						x	x					
Water Vietnam - ADB	191								x				x			x				x								x		
TRMs included as good practice, but not related to Climate Change																														
ITRS TRM on semiconductors	996																													x
TRM on power grids -DoE	998																											x		

66. Within this selection of good practice TRMs, we consider the IEA TRM structure a 'best practice' standard, which we present and discuss in section 6.1, using some concrete examples from the IEA Wind TRM. However, the other selected TRMs show specific strengths that are complementary to the IEA structure, or are particularly useful in specific contexts. These specific features are presented and discussed in Section 6.2, in which examples are discussed both from the other selected TRMs related to climate technologies, and from the TRMs non related to climate technologies.

6.1 The IEA TRM format

67. The IEA TRMs aim to identify the primary tasks that must be addressed in order to reach the IEA vision for specific energy technologies, such as wind, solar-PV and CSP, bioenergy, electric vehicles, and others. In their descriptions of current status and future vision, they make ample use of statistics and models available within the IEA, which gives the TRMs a strong quantitative basis. In the IEA TRMs, concrete tasks and milestones are defined on the basis of the vision, and they are allocated to specific actors. By strong involvement of stakeholders in the TRM process, stakeholder buy-in is aimed for. Not all IEA TRMs specifically mention the names and/or affiliations of the stakeholders who were involved in their production.

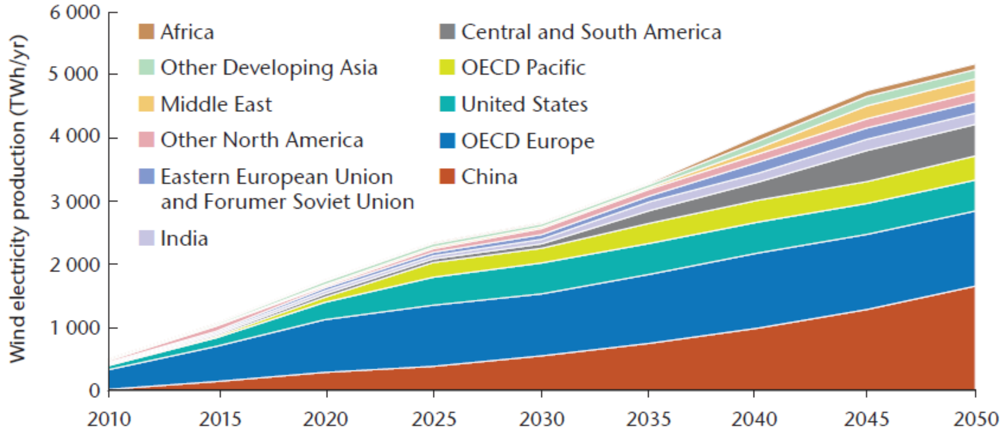
IEA TRM Structure:

68. A typical IEA TRM has the following structure:

1. A *Technology status of today* chapter, describing deployment of the technology in the past decades, its performance and costs. Depending on the technology, other elements in this section can be market trends, specific technological and R&D issues, system integration and public acceptance issues.
2. A *Vision for deployment*, which discusses the foreseen future capacity of the technology, its share in the future energy mix, and projected cost reductions. Also aspects such as investment needs, grid linkages, and non-technical challenges are discussed in this section.
3. Several *Actions and Milestones* sections go into actions and milestones related to various issues identified in earlier sections. For example, the Wind TRM has Actions and Milestones sections on:
    - Wind Technology Development and Deployment:
    - Delivery and System Integration
    - Policy Frameworks
    - International Collaboration
4. *Finally there is a Roadmap action plan and next steps,* in which the actions and milestones are allocated to specific actors, such as industry, government, universities and intergovernmental organisations. The wind TRM has these for the energy industry, governments and the power sector.

Specific strong features: Targets

69. All IEA TRMs are based on extensive modelling results from earlier IEA studies (IEA 2008), and provide quantitative information on projected market shares, costs and investments. Figure 3 gives an example of this, showing projected wind power production levels in different regions in the world. Also targeted future cost reductions and required investment levels in wind power are projected, providing a broad and quantitative basis for the remainder of the TRM.



Source: IEA (2008a).

KEY POINT: Leading markets over the period are China, OECD Europe and the United States. OECD Pacific countries gain importance after 2020, and Central and South America after 2030.

Figure 3: Regional production of wind energy projection, as part of the vision section of the IEA wind energy TRM (IEA 2009)

Specific strong features: Actions

70. The IEA TRM format for actions and milestones is comprehensive, structured but simple, time-specific and actor-specific. While it does not link the actions visually back to key challenges coming from the targets section, the accompanying texts in the TRM do provide this link. The table format it is a good way of structuring the key outcomes of the TRM. Figure 4 shows a part of the actions to be led by governments from the wind TRM (IEA 2009).

R&D Finance	Milestones and actors
1. Identify and provide a suitable level of public funding for wind energy R&D, proportionate to the potential of the technology in terms of electricity production and CO_2 abatement.	From 2010. Iterate over 2010-2050 period. Governments, research institutions and industry.
Education and employment	
2. Develop internationally standard education and training strategies for the complete range of skills needed, from design to deployment.	Complete by 2015. Governments, universities, and industry.
Deployment incentives	
3. Where not already in place, establish long-term targets for renewable energy deployment, including short-term milestones.	Complete by 2015. Governments with input from industry.
4. Implement support mechanisms that provide sufficient incentive to investors; develop effective systems to internalise the external costs of all forms of electricity production into market prices for electricity.	Complete by 2015. Governments with input from investors and financiers, research institutions and regulators.
Transmission development	**Milestones and actors**
5. Provide incentives for accelerated construction of transmission capacity to link wind energy resources to demand centres (using new latest proven technology); establish mechanisms for cost recovery and allocation.	Complete by 2015. Governments, wind developers, transmission companies and system operators; regulators.

Figure 4: Actions and milestones to be led by governments in the IEA wind TRM *(IEA 2009, detail)*

6.2 Good practice examples from other TRMs

71. While the IEA format provides an excellent TRM standard, inspiration for specific elements can also be found in the other good practice examples we analysed. Here, we show some good examples of specific methodologies, ways of target setting, structuring of actions and visual representation. Short descriptions of these TRMs can be found in Annex 4.

Elaborate methodology: The Crystal Faraday Partnership TRM on Green Chemistry

72. Sometimes it is not clear what direction the development of a certain technology should take, and how this development should link to fundamental societal developments. In such cases it is important to have a trend analysis as starting point of the TRM. The Crystal Faraday Partnership TRM on Green Chemical Technology (document no. 179 see Table 6) provides a good example of such an exercise. This TRM used an elaborate method, starting with an identification of basic (societal, technical, environmental and other) trends and drivers. It then links these trends and drivers to consequent future requirements to chemical products and processes, identifying key technology characteristics. It ends with a review of key R&D challenges and corresponding gaps in current R&D. See also Figure 5. The strength of such an outside-in approach is that it contributes to the societal relevance and value added of a TRM.

Setting targets when extensive modelling tools are not available: the PV TRM for China

73. It is not always possible to generate such extensive quantitative analysis as in the IEA TRMs, particularly in non-Annex 1 countries. The PV Power TRM on PV in China (doc. no. 59) uses a practical approach on this: the projections of global and regional development of PV (from an IEA study) are translated into specific national objectives for China. Although such translations will need to be done with careful attention for the specific characteristics of a country, they can be a pragmatic way of generating some quantitative basis.

Well-structured actions table: the UK TRM on Fuel Cells

74. Overviews of actions in a TRM are most valuable when they clearly link to the issues that need to be addressed, and the strategies to be applied. The UK TRM on Fuel Cells (doc. no. 109) is a good example of this linkage: the document contains comprehensive tables translating challenges to strategies and actions, also pointing out champions for each action and required timing. This was done for four areas: (i) Regulation and policy, (ii) market development, (iii) education, training and awareness, and (iv) technology development. This provide a well-structured basis for concrete actions at a specific level, and also for more the more generic recommendations in the TRM. Figure 6 shows an example part of these tables.

From targets to actions: the SEAI TRM on Electric Vehicles

75. Another way of strengthening internal consistency in a TRM is by integrating targets and actions into one figure with a shared timeline. The Sustainable Energy Authority of Ireland (SEAI) TRM on Electric Vehicles (doc. no. 61) provides a good example for this. The core of this TRM is a comprehensive and complex deployment scenario scheme that integrates market projections with required actions.

76. Figure 7 shows an excerpt from this scheme, with the scenario graph and the actions for policy and technology (actions on charging infrastructure and grid& wind infrastructure not shown in this excerpt).

Linking drivers and actions in one illustration: the Bonneville Power Administration TRM on efficiency technologies

77. Linking actions to essential trends and drivers can also be done through a visual scheme. The Bonneville Power Administration TRM on efficiency technologies (doc. no. 9) contains such visuals. They show how basic societal drivers are translated into desired product features. These are then translated into technology challenges, which lead to R&D challenges. This structured way of thinking is important for TRMs, and provided a good basis for the final step, not shown in the visual: the identification of concrete actions for BPA. Figure 8 shows and example scheme from this TRM.

A concise approach in case capacity is a limiting factor: the Viet Nam Water TRM

78. Of all TRMs reviewed, only a few relate to non-Annex 1 countries. Of these, the Viet Nam TRM on Water (doc. no. 191) is one of the better examples. It is a concise document (15 page total) in which the tabular material is well structured (see also Figure 9). Three tables cover the major part of a TRM flow:

1. *Sector Outcomes*, specified for three subthemes, with indications of the developments in the past 5 years, the current situation, and indicators for success in 5 and 10 years.
2. A S*ector Outputs* table, in which the desired outcomes are transferred in more practical ambitions.
3. An *Issues and Constraints* table, discussing regulatory, institutional, infrastructural and other barriers.
4. An *Actions, Milestones and Investments* table, including a time schedule and an identification of the role of ADB and other parties.

The importance of well-structured workshops as part of the TRM process: The DoE TRM on Power Grids

79. Particularly when stakeholders with different interests need to be united in a TRM with a clear common interest, workshops will be an important part of the TRM process, and they need to be well prepared. In order to develop a shared vision and set of actions on modernizing the power grid in north America, the US Department of Energy convened a series of two one-day workshops bringing together over 250 industry professional to generate an 'action agenda'. They did this in two steps:

- The first workshop brought together senior executives and policy makers to develop a 'vision' of the future.
- The aim of a second workshop attended by technical experts was on building a consensus on how to achieve the vision.

80. This resulted in a TRM that was backed by industry both in terms of its desirability and in its achievability (see doc. no. 998 for more information).

The importance of updating: The International Technology Roadmap for Semiconductors (ITRS)

81. A TRM provides an outline and framework for action in technology development and deployment. However, as this framework covers time periods of sometimes more than three decades, and the world changes, regular updating is a valuable thing to do: it safeguards that the TRM remains up to date and relevant as a guiding document.

82. A clear example of this is the International Technology Roadmap for Semiconductors (ITRS, doc. no. 996). The ITRS has been updated annually since 1991. Having started as a US initiative, the scope was broadened to include other nations owing to the global nature of the industry. It is the most authoritative source on the industry's research and development needs over a 15-year horizon. Schaller (2004) demonstrated the benefits of this initiative, in terms of standards setting and enhanced rates of innovation, in a detailed account of the evolution of the ITRS. The updates are well traceable: in each update document there is a specification of the specific elements that were changed in comparison to the earlier version of the document.

Step 1	*Identify key industry trends and drivers* Key industry trends and drivers were identified using the STEEP model (social, technical, economic, environmental and political forces). This was done for general trends and drivers and those specific to a particular sector. Four time periods were considered: • History: 1998-2002 • Short term: 2003-2007 • Medium term: 2008-2012 • Long term: 2013-2023+
Step 2	*Identify goals plus features and attributes by sector* For each of the four sectors in the chemical industry, list the specific sustainability goals of the sector in response to the trends and drivers. Identify the features and attributes required in products, services and manufacturing processes to meet the sector goals. Group these into the three future time horizons.
Step 3	*Group the features and attributes across the sectors* Group the features and attributes identified in Step 2 into a smaller number of product and manufacturing key goals that apply across all sectors.
Step 4	*Map technology areas to key goals and attributes* For each of the eight technology areas rate the impact on the key goals and attributes.
Step 5	*Identify the key technology clusters for each sector* Using the analysis in Step 4 we can identify which technology clusters are most important for each sector of the industry.
Step 6	*Build technology roadmaps for each technology area* For each technology area now identify the technologies that can be implemented in the short term with immediate benefits, and those key technologies that need further development. Dependencies and constraints are recorded for each roadmap.
Step 7	*Identify gaps and priorities* The key technology requirements to meet future industry needs are in the roadmaps. Compare these to existing programmes to identify gaps in the existing portfolio, leading to recommendations for focus and investment.
Step 8	*Key messages for audiences* What are the key messages for the target audiences? • industry; • academia; • government.

Figure 5: Methodology of the Crystal Faraday partnership (2004) TRM on Green chemistry

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
7. Insufficient access to market-based mechanisms	Portfolio of complementary market mechanisms to provide long term support for the development and deployment of fuel cells	Adapt market mechanisms to reflect benefits which fuel cells bring.	i) Explore options for extending the Renewable Obligation Certificate scheme to allow a small proportion of highly innovative electricity generation (beyond renewables), with significant potential to deliver benefit, to receive a greater incentive (e.g. 20p/kW).	i) Defra	i - ii) Short term
			ii) Ensure that fuel cell installations benefit from Levy Exemption Certificates (LECs).	ii) Fuel Cells UK	
			iii) Factor the role of fuel cells into renewable energy systems eligible for Renewable Energy Guarantees of Origin (REGOs) (e.g. biofuels-fuelled systems) as well the potential for emissions trading of bundled installations.	iii) ENCG with support from Fuel Cell Coordination Group (see Challenge 3)	iii) Short to medium term
8. Ensuring policy develops in line with evolving market conditions	Flexible and responsive policy framework	Introduce mechanisms to integrate lessons from national and international experience into the evolving policy framework.	i) Where appropriate adopt international best practice in removing regulatory barriers to fuel cell development and deployment, including fuel infrastructure aspects.	i - ii) Central Government, led by Fuel Cell Coordination Group (see Challenge 3)	i - iv) Ongoing
			ii) Support UK learning from international activity (e.g. demonstrations and procurement initiatives) by funding International Missions etc.		
			iii) Ensure that lessons from trials, demonstrations and research are fully understood and reflected in evolving policy framework through periodic briefings and updates to Departments, Ministries and Parliamentary Office of Science and Technology.	iii) Fuel Cells UK	
			iv) Undertake periodic and systemized review of general and specific policy.	iv) Central Government (led by Fuel Cell Coordination Group)	

Figure 6: Sample Table from the UK Fuel Cells TRM *(Fuel Cells UK 2005)*

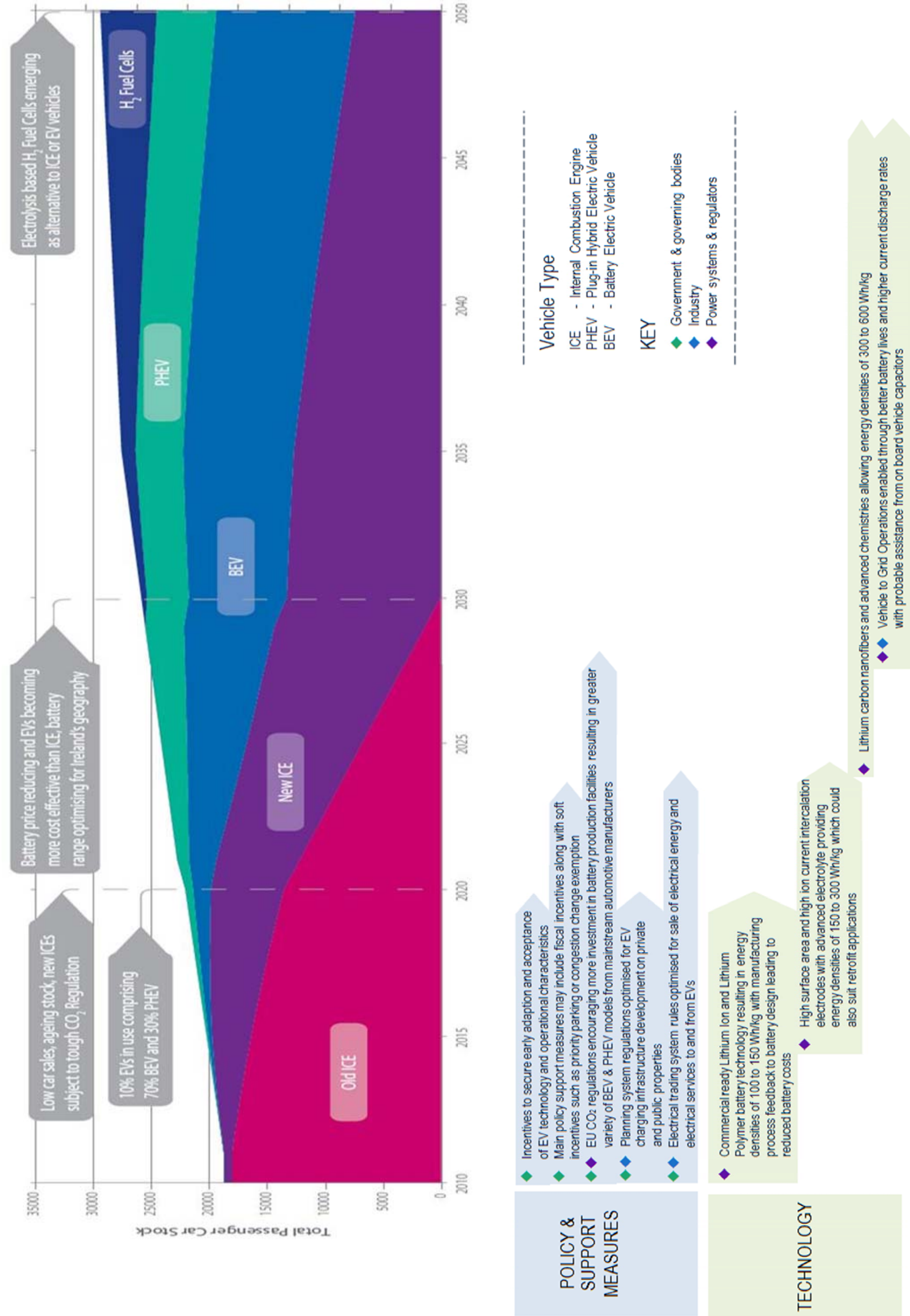


Figure 7: Excerpt from the EV deployment scenario and actions in the SEAI Electric vehicles TRM *(SEAI 2011)*

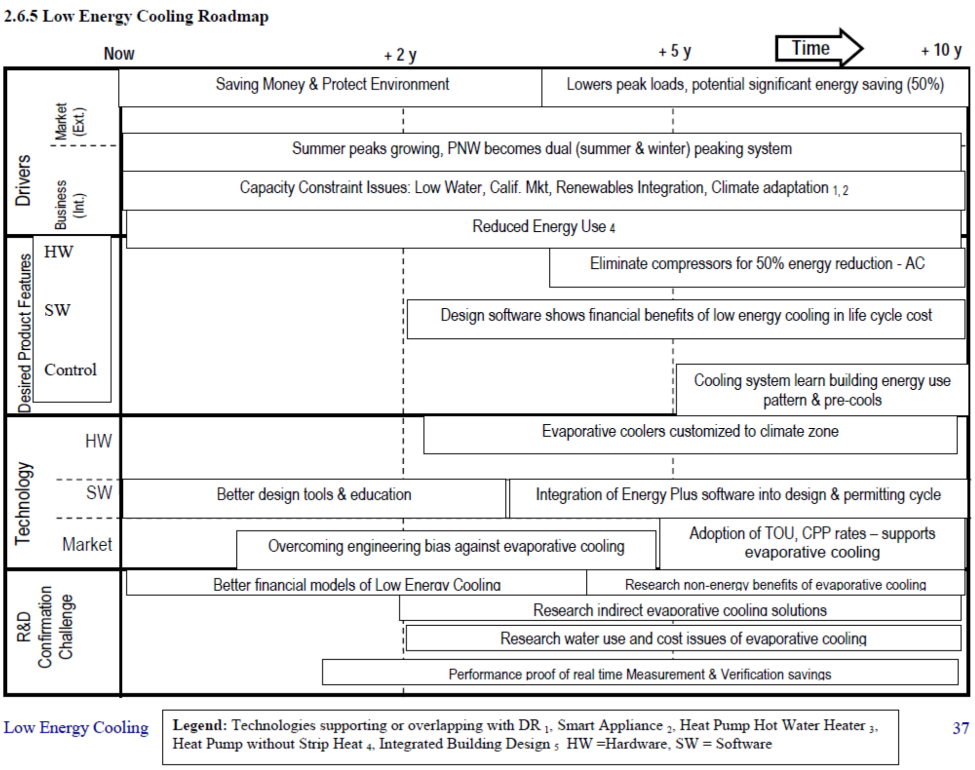


Figure 8: Visual element from the Bonneville TRM on energy efficiency technologies *(Bonneville 2006)*

D. Actions, Milestones, Investments	By Issue	Schedule	ADB	Others/ External
D.1.Viet Nam Actions, Milestones and Investments				
D.1.a. Water Resources Management				
TA3528-VIE Component 1: National Water Resources Coordination Project	▪ Policy and Legislation ▪ Institutional Arrangements	2001 - 2004	Technical Assistance	
TA3528-VIE Component 3: Dong Nai River Basin Water Resources Management	▪ Institutional Arrangements ▪ Deteriorating Water Quality ▪ Increasing Competition for Water ▪ Watershed Degradation	2003 - 2004	Technical Assistance	
Vietnam Water Resources Management Assistance Project	▪ Institutional Arrangements ▪ Information Management	2001 - 2004		AusAID
Water Sector Program Support	▪ Policy and Legislation ▪ Institutional Arrangements ▪ Increasing Competition for Water ▪ Deteriorating Water Quality	2001 - 2005		Danida
Study on Nation-Wide Water Resource Development and Management	▪ Increasing Competition for Water ▪ Infrastructure	ongoing		JICA
National Hydropower Plan Study	▪ Increasing Competition for Water ▪ Infrastructure	First phase completed in 2002; second phase to start in 2003		Funded by Sweden and Norway

Figure 9: Excerpt from the Actions, Milestones and Investments table in the ADB Water TRM for Viet Nam *(ADB 2003)*

7. Technology road maps in the area of adaptation

83. The characteristics of technologies for adaptation are to some extent different from technologies for mitigation. Many adaptation technologies are termed 'soft' technologies, e.g. practices, management strategies and behavioural patterns, potentially in combination with hard technologies, such as dams and other infrastructure investments. In least-developed countries especially, adaptation measures (and their related technologies) can be closely linked to development strategies. The secure provision of basic services such as water, food, health care, education and access to energy for example tends to increase climate resilience in these areas, particularly for the poor. The technical paper "Application of environmentally sound technologies for adaptation to climate change" (UNFCCC 2006) demonstrates that a need for adaptation cannot be considered in isolation; typically, adaptation is closely linked to other needs and policy issues, such as spatial planning, food security and public health.

84. The choice for adaption technologies is generally based on an assessment of a country's vulnerability to climate change. There are many uncertainties around most methodological steps of these vulnerability assessments, three examples are summarise here. Firstly, debate exists around global temperature increases, and the resulting effects (sea level rise, more extreme weather events such as hurricanes, melting of glaciers). Secondly even higher uncertainties exist around the local climate impacts that stem from the global changes (e.g. rain fall distribution patterns, local temperature changes and distribution). Finally, uncertainty exists around the impact of local climatic changes on local eco-systems, agricultural productivity etc. This distinguishes any adaptation assessment and strategies from mitigation related actions where it can be more reasonably assumed that any reduction in GHG emissions will have a positive impact on the global climate. Due to the large uncertainties around local climate impacts it has even been suggested to only undertake large-scale investments into adaptation technologies now, if the technologies are not only justified by consideration of future climate change, but are also needed to meet today's needs (Smith, 2006).

85. The technical paper "Application of environmentally sound technologies for adaptation to climate change" (UNFCCC 2006) describes the challenges of technology transfer for adaptation, and stresses that there are several important distinctions between the processes of mitigation and adaptation, e.g. adaptation is not new in the way that mitigation is new, the sectors that need technology for adaptation are ubiquitous, and many (though not all) technologies for adaptation are already readily available in developing countries. These distinctions imply that TRMs should play a different role in adaptation than they do in mitigation.

86. Our review of TRMs for adaptation has the following results: Firstly, a very limited number of TRMs on adaptation was found (only 11 of the 159 TRMs analysed; 8 of these 11 focus on water resource management). The reasons behind this are uncertain. It is possible that planning efforts related to adaptation are limited at present, and therefore technology needs have been less clearly specified. Moreover, it may point to the fact that globally fewer resources have been spent with the primary focus on adaptation than on mitigation to date, and that consequently there are, amongst others, less specialist knowledge and skills, and a lack of good practices guidance. Finally, the difference may originate from adaptation being less focused on "hard" technologies than mitigation.

87. Secondly, in the identified TRMs, the attention for technology R&D is generally limited: in TRMs related to water for example, a central focus is on policy and resource

management approaches. The only TRM with a clear technology R&D focus is the Australian TRM on water desalination.

88. Because of the limited set of adaptation TRMs, only relatively tentative conclusions can be drawn. Within the selection of adaptation documents analysed, there is a dominance of TRMs related to water. However, there were too few TRMs to draw a definite conclusion that this sector is specifically suitable for TRMs.

89. On the basis of the more common insights on TRMs generated in this study, some more general observations on TRMs and adaptation technologies can be made.

- TRMs are a useful tool when development and transfer of technology plays an important role, and when stakeholders from different backgrounds need to be activated. In the field of adaptation, TRM therefore seem most suitable for so called “hard” technologies rather than for practices, management strategies and behavioural patterns.
- Adaptation interrelates with other policy themes more strongly than mitigation and can have a strong link to development. Therefore, the diversity of stakeholders to be engaged will be greater than for mitigation options. TRMs will require most careful attention for this engagement process.
- Adaptation technology roadmaps must deal with the inherent element of uncertainty related to the assessment of a country’s vulnerability to climate change. This can be addressed by regularly updating not just the technology roadmap itself, but also the underlying scenarios for expected climatic changes and their consequences in a country.
- Adaptation TRMs are most relevant at the national level, a conclusion tentatively confirmed by the limited set in this review. TRMs are supposed to be prepared in order to accomplish specific (quantifiable) goals; clearer objectives usually lead to more impact of the TRM. Ideally, countries envisaging potential negative impacts of climate change plan the relevant adaptation efforts, define the expectations regarding technologies to support these efforts, and develop TRMs accordingly. Specific technology needs would vary between countries and thus adaptation technology roadmapping efforts are probably most effective at country level. These efforts could be linked to TNAs and TAPs.

90. Due to the few adaptation TRMs analysed in this study, limited new insights on adaptation TRMs are presented in this background paper. This would suggest that an additional activity should be considered to address specific questions regarding adaptation TRMs. A dedicated workshop with a selection of invited adaptation experts would strengthen these conclusions and recommendations.

8. Key conclusions

91. In our key conclusions, we discuss general advantages and limitations of using TRMs (8.1), the gaps and other challenges in TRMs found in the review (8.2), and other key findings (8.3).

8.1 Advantages of using TRMs

92. Based on the literature review undertaken in this study, the review of TRMs and the common insights of the authors, the following presents some of the key advantages and limitations of using TRMs. Advantages include the following:

93. The key distinguishing feature of technology roadmapping is the structured depiction of trends, objectives and actions. This can take many forms ranging from tables to pictorial representations. Such depictions provide a highly synthesised view of strategy that is beneficial for supporting dialogue and communication between stakeholders. These benefits occur both during the roadmap development process and subsequently for dissemination of strategy and policy.

94. The origins of technology roadmapping lie at the firm level, for aligning technology and product strategy, although the method has subsequently been extended to general business strategy. The roots of the method as practical 'tool' for supporting technology and innovation management make it particularly suited to supporting technology management, and to link technological considerations to policy.

95. In contrast with many traditional methods (see also Section 3), technology roadmapping has been identified as being pro-active (de Laat & McKibbin, 2003), "starting from the idea that the future can and should be created – therefore it is not lead by technological determinism".

96. The roadmapping method is typically characterised by a strong consensus-building process, led by a shared vision and agreed actions. The action-oriented nature of the method is reinforced by the most common visual representation of a multi-layered time-based diagram, somewhat similar in architecture to project planning tables, such as Gantt charts.

97. The strong consensus-building element of roadmaps could make them a useful tool for the work of the Climate Technology Centre as well. With respect to facilitating the Climate Technology Network to enhance cooperation with national, regional and international technology centres and relevant national institution, facilitate international partnerships among public and private stakeholders to accelerate the innovation and diffusion of environmentally sound technologies to developing country Parties and provide technical assistance and training to support identified technology actions in developing country Parties.

98. Roadmapping is a flexible approach, underpinned by the generic systems-based roadmap architecture. This enables the method to be applied in many different circumstances, with both the roadmap structure and roadmapping process adapted to suit the particular context, with the capability of integrating the method with other methods, such as scenario planning and portfolio management The advantage of this flexibility also represents challenges, as there is no standardised and generally accepted approach, so skills and experience are needed for effective application. There has been a proliferation of activity, including many examples of good and bad practice. The flexibility of the road mapping approach may make it especially suitable in the context of the work of the Technology Mechanism, which addresses technology

development and transfer in a large variety of different country contexts and for very different types of technologies.

8.2 Limitations of using TRMs

99. There are also a few limitations of the TRM approach. A TRM process aims at reaching consensus on a vision of the future. This creates a risk for a 'lock-in' or tunnel vision: overly focusing "in the direction of one single collective future vision", reducing the attention for uncertainties, variety and diversity, which are healthy aspects of many strategic initiatives (de Laat & McKibbin, 2003). This needs to be guarded against as part of the TRM process design and governance. For this, De Laat & McKibbin (2003) highlight a number of such 'key success factors' associated with the initiation, implementation and follow-up process phases:

1. Initiation: establishing a clear need; visioning and goal setting; integration with broader policy strategy; commitment and support from decision makers; engagement with the appropriate network of stakeholders.
2. Implementation: the need to customise the method and to retain flexibility through the process; maintaining momentum; a culture of openness; and adequate levels of programme funding.
3. Follow-up: iteration, to refine and update the roadmap; monitoring outcomes, uptake and impacts.

100. Another limitation, or important precondition, is that a TRM will only be successful in implementation if it aligns well with existing (governmental) plans and strategies. For the feasibility of the identified actions in a TRM, this is an essential element.

8.3 Gaps in existing TRMs and possible challenges

101. This section summarises the key findings from the analysis of climate change mitigation and adaptation technology related TRMs. Three conclusions stand out from the analysis, and set the most significant challenges for the TEC. The first conclusion lies in the clear gap in TRMs developed by or for Non-Annex I countries. The second is the low representation of adaptation technologies. Third, excluding some good practice examples, there is room for improvement with respect to the methodological approach and process in the analysed TRMs.

- The vast majority of TRMs are authored by Annex I countries with a national focus. There are to a lesser extent TRMs from international authors that are geographically unspecific, and could be relevant in non-Annex 1 countries, however the Non-Annex I specific TRMs are limited to only 5% of the total.[4]
- Of the TRMs analysed, mitigation technologies dominate. Within the set, mentions of adaptation technologies (G) make up only 5% of the total[5]. This

[4] See Matrix 1, available in the Annex. There are 21 technology mentions from TRMs authored or sourced from Non-Annex I countries.

[5] See Matrix 1, available in the Annex. There are 21 mentions of adaptation technologies (G) out of a total of 436 mentions of technologies.

sits in stark contrast to over 30% for renewable technologies (A1) and 30% for other energy technologies (A2).

- The majority of TRMs analysed lacked key elements considered essential for successful TRMs. A lack of clear vision, quantifiable targets and actions hampers the potential for even the best-intentioned TRMs to deliver meaningful beneficial change.

8.4 Other conclusions

102. The discussion on TRMs vis-à-vis other strategy tools shows that technology roadmapping partly overlaps with several of them, but has its unique features. TRMs are more action-oriented than scenarios and forecasts. Backcasts resemble TRMs more closely, but backcasts usually sketch a more storyline-like vision of the future, while TRMs usually focus on the future of a specific technology. National (policy) TRMs differ from industry TRMs in the level of complexity they have to address; as a consequence, TRMs for policy usually have an objective that is more broadly defined than in private sector TRMs, and also the required actions are more generic.

103. TRMs can serve several purposes. We have identified six purposes potentially relevant to the TEC: (i) provide coherent input to (inter)national technology R&D policy, (ii) provide a basis for national policy supporting diffusion of climate technologies, (iii) be a catalyst for existing technologies to adapt to new markets, (iv) mobilise private sector interest in climate technologies, (v) provide a common platform for international support, and (vi) generally aligning actions by different funders and ministries.

104. Methods and guidelines for TRM processes and documents are available, both for application at corporate and (inter)national level. For the latter, the IEA guidelines are particularly illustrative.

105. Also, good practice examples can give guidance to TRM developers. The IEA format is a typical reference, but other TRMs show useful examples for cases in which e.g. underlying societal trends need to be analysed in more detail, quantitative analysis for deriving a target are not available, or when financial resources are very limited.

106. Regarding adaptation, we found only a limited number of TRMs on this matter, mainly on water. Our impression is that technology plays a different role in adaptation than in mitigation; adaptation more often making use of existing technologies. Also adaptation measures interrelate more strongly with other policy themes than mitigation options do.

8.5 Limitations of this study

107. There are some essential limitations to this study, particularly to the review of TRMs.

- We have used a limited set of TRMs. Given the wide application of TRMs, our list is definitely not exhaustive.
- Only TRMs in the English language were reviewed, which is illustrated by the absence of e.g. German and French TRMs. This leads to a bias towards English speaking countries in our list.
- The analysis has a strong focus on TRMs for climate technologies. While we have introduced some examples from other types of technologies, more guidelines and good practices are certainly available.

- Certain (climate-related) technologies might be included in TRMs with more general names, concealing the climate-related aspects in them. We have not been able to identify such TRMs.
- Some TRMs might be not be available on the Internet but only in printed form
- Some TRMs may are not available in the public domain; this particularly applies to industry TRMs.

Our study focused mostly on quantity of TRMs. Of course, the impacts of specific TRMs are incommensurable, e.g. one good TRM could have far more reaching outcomes than several poor TRMs (in terms of structure and/or process). As our analysis indicates that most of the TRMs reviewed are rather far from the ideal, their counts are not good predictors of actual implementation-related activities all over the world.

9. Recommendations for TEC activities on TRMs

108. The literature reviewed and analysis conducted highlight many areas that must be addressed. The following section lays out recommendations. We structured the recommendations to address three questions:

1. What are the specific needs or areas regarding development and use of TRMs in the context of addressing climate change?
2. How could the TRM approach be integrated into current efforts for enhancing technology transfer and actions for mitigating and adapting to climate change, such as TNAs, NAPAs and NAMAs?
3. What role could the TEC play as the policy arm of the Technology Mechanism? How could the work of the TEC be conducted in a more efficient and meaningful manner including by taking advantage of existing efforts and cooperating with relevant organizations and institutional arrangement under the Convention?

Actions are further summarised in the table at the end of this section

9.1 Specific needs regarding TRM development and use in the context of addressing climate change

109. Despite the wealth of TRMs available, it is clear from the review in Sections 4 and 8.2 that important gaps exist in (i) technology areas, (ii) time horizons, and (iii) the geographical scope of existing TRMs. Of particular note, few TRMs deal with the specific context of non-Annex I countries, and with technologies to adapt to the predicted consequences of climate change. Given the importance of developing countries and of adaptation, there seems to be a need to fill these gaps.

110. The absence of several relevant elements in many existing TRMs hinders their potential contribution to climate change adaptation and mitigation technology transfer. In order to improve a TRM's impact and success, there seems to be a need for more guidance on good-practice TRMs and TRM processes.

111. The analysis shows that good practices are possible within various constraints in terms of time, available data and budget. But as good practice guidelines mainly focus on developed countries, there seems to be a need for a good practice guideline on producing a TRM in a developing country.

112. However it must be recognised that simply providing guidance may not be suitable in certain circumstances. The TRM process is complex and requires a facilitator to achieve the best results. There might be a need for more practical coordination in the running of structured workshops or training sessions in order to build capacity for TRM development, before any future TRMs are conducted.

113. Generally, for developed and developing countries, budgets can be a constraining factor for TRMs. Therefore, there seems to be a general need for a process and guidelines to meet the needs of small scale cost efficient TRMs.

9.2 Integrating TRMs in other technology transfer efforts

114. TRMs are only one of several tools supporting actions for mitigating and adapting to climate change, and related technology transfer. So it is important to know how these tools interlink and integrated. Here we focus on TNAs and NAPAs/NAMAs

115. The Technology Action Plans developed as part of the latest round of Technology Needs Assessments under the UNFCCC deploy a method very similar to a

TRM approach, as the Technology Action Plans intend to clarify priorities, set milestones, identify barriers to technology development and transfer and develop measures to overcome these barriers. However, TAPs from different countries still vary widely in scope, degree of detail and readiness for implementation (partly because the implementation success of TAPs depends on the (uncertain) availability of finance). TAPs are also prepared for multiple technologies, while TRMs are mostly concentrated on individual technology areas. TRMs could help translate TNAs and TAPs into action, by defining timelines and milestones. Besides, a well-prepared and realistic TRM could show potential investors or international donors that the authors and stakeholders understand the complexity of a technology development process and commit to their role in it. An important question is also how roadmaps can be integrated into other climate instruments like Nationally Appropriate Mitigation Actions (NAMAs) and National Adaptation Programmes of Action (NAPAs). As our findings on adaptation technology TRMs are very limited, we here focus on the integration with NAMAs.

116. NAMAs, introduced in Bali in 2007, have received increasing attention in the past years (Van Tilburg et al. 2012). There is however still not much information available on definitions of NAMAs, and they can take the form of a strategy, policy or concrete project (Van Tilburg et al. 2012). That also makes it difficult to define how NAMAs and TRMs can be linked. But some suggestions can be made:

- If NAMAs take the form of policies or projects, TRMs can provide an overarching framework for development and/or transfer of a specific technology in which different NAMAs play a role. In such a case, a TRM and its process can align various NAMAs and other activities needed to allow a technology to reach implementation. National governments could use TRMs in this function, the TEC could support this.
- If NAMAs take the form of more generic strategies, they might be overlapping (if the NAMA focuses on a specific (set of) technologies or complementary (if the NAMA focuses on cross-cutting issues). In both cases, strong interlinking will be needed.

9.3 Potential roles of the TEC in promoting technology roadmaps

117. On the basis of our review, we can provide some broad topics or priorities for the TEC to promote further improvement and use of TRMs. On the basis of sections 9.1 and 9.2 we recommend:

- Given the gap identified with respect to TRMs focusing on non-Annex I countries, there is a role for the TEC to promote the use of TRMs in these countries.
- Comparably, the TEC could further investigate the perspectives for promoting TRMs on adaptation technologies
- As many TRMs reviewed can still greatly improve their quality, disseminating best practices and guidelines would also be a valuable role for the TEC.
- For TRMs in developing countries, the TEC could also initiate the development of a specific guidance document that takes into account circumstances and constraints in developing countries, e.g. the fact that the detailed technology modelling which forms the basis for IEA roadmaps may not be available.
- Where relevant the TEC could consider coordinating the running of structured workshops or training sessions in order to build capacity for TRM development before any future TRMs are conducted.

- The TEC could generally consider initiating the production of TRM guidance for small-scale low-budget TRMs
- TRMs and TNA/TAPs are approaches that seem to be relatively comparable. Therefore it is important that the TEC interacts with the parties supporting and producing and TNA/TAPs in order to mutually learn from experiences and share good practices.
- Depending on the direction that the further development of NAMAs will take, there will be either overlap between NAMAs and TRMs or TRMs could act as overarching frameworks for NAMAs. It seems recommendable for the TEC to stay on top of developments in the NAMA community, and search for synergies, e.g. by organising a dedicated activity on the links between NAMAs and TRMs.

118. Additionally, we have formulated some other recommendations on the basis of the analysis in this paper.

- The TEC, or other institutions under the UNFCCC could provide support to developing countries on how to include elements of technology roadmapping exercises in existing national planning processes in order to avoid undue strain on government capacity and the proliferation of a large number of strategy documents.
- As for the various potential purposes of a TRM in the context of technology development and transfer, the TEC or other institutions under the UNFCCC might pay specific attention to the TRM purpose of aligning activities of various donors and ministries in the development and implementation of a technology. The TEC could add value by supporting TRMs with this purpose, or by supporting the development of specific guidelines for TRMs.

9.4 Summary of Recommendations

119. Table 7 sets out a summary of the recommendations made in section 9 detailing the issue identified (in the literature and/or analysis), and the recommended action and actor.

Table 7: Summary of recommendations

Issue	Recommended action
Need for TRMs developed for or by Non-Annex I countries	Promote the use of TRMs in developing countries
Lack of TRMs developed on climate change adaptation technologies	Explore the perspectives for promoting adaptation TRMs
Various substantive elements essential for TRM missing	Disseminate guidance on good practice TRM development
Need for specific guidance for TRMs in developing countries	Initiate the development of a TRM guidance document specific for developing countries
Lack of capacity in organising TRM workshops	Training and capacity building for organising TRM workshops and other activities
Lack of guidance on Low Cost (relative) TRM development processes	Initiate good practice guidelines for small-scale low-cost TRMs
Comparability between TRMs and TNA/TAPs	Interaction between TEC and TNA/TAP supporters for mutual exchange of experiences and learning
NAMAs could be comparable with TRMs or TRMs could become frameworks for NAMAs	Organise specific activity on exploring the potential synergies and overlaps between NAMAs and TRMs
Need for harmonising TRM outcomes with national planning processes	Provide support on harmonising TRM outcomes with national planning processes
Use of TRMs for harmonising activities by various donors and ministries within one country could be improved	Provide support on the use of TRMs for harmonising activities by various donors and ministries within one country

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Annex

Annex 1 - **List of TRMs analysed**

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
1	Realization of global-scale thorium breeding fuel cycle by single molten-fluoride flow	International Conference on Emerging Nuclear Energy Systems	2007	Nuclear	International	Roadmap for introduction of innovative thorium based nuclear fuel cycles
2	A technology roadmap for generation IV nuclear energy systems	Generation IV International Forum	2002	Nuclear	International	Roadmap for next generation nuclear systems in 2020
3	Accelerated and extended Japanese pv technology roadmap PV2030+	RTS Corporation	2009	Photovoltaic	Japan	Roadmap for accelerated development of photovoltaics in Japan
4	Canada's clean coal technology roadmap	Natural Resources Canada	2009	Clean Coal	Canada	Canadian Clean Coal roadmap
5	Canada's CO_2 capture and storage technology roadmap	Natural Resources Canada	2009	Carbon Capture & Storage	Canada	Canadian Carbon Capture & Storage roadmap
6	Cement technology roadmap 2009	International Energy Agency	2009	Cement	International	Roadmap for cement emissions reduction to 2050
7	Clean Coal technology roadmap	Department of Energy	2000	Clean Coal	USA	Roadmap on Clean Coal in USA
8	Cool earth - innovation energy technology program	Japanese Ministry of Economy, Trade and Industry	2008	Energy Supply	Japan	Roadmap for technologies and international cooperation
9	Energy efficiency technology roadmap	Bonneville Power Administration	2006	Energy Supply	USA	Roadmap by Bonneville for energy efficiency technologies
11	Energy technology vision 2100	International Energy Agency	2006	Renewable	Japan	Vision for a renewable energy future by 2100
12	Hydrogen technology roadmap	Department of Resources, Energy and Tourism	2008	Hydrogen	Australia	Australian roadmap for hydrogen energy

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
13	National hydrogen energy roadmap	US Department of Energy	2002	Hydrogen	USA	Roadmap for hydrogen energy in response to Bush administration national energy vision
14	On investing in the development of low carbon technologies: a technology roadmap	European Commission	2009	Renewable	EU	Roadmap by European commission for renewable energy until 2020
15	Power services roadmap	Bonneville Power Administration	2008	Energy Supply	USA	Roadmap by Bonneville for quality of power service
16	Renewable energies in the 21st century: building a more sustainable future	European Commission	2007	Renewable	EU	European commission renewable energy roadmap until 2020
17	Renewable energy industry roadmap of Spain	American Public Power Association	2010	Energy Supply	Spain	Roadmap on renewables for Spain until 2020
18	Renewable energy technology roadmap	Bonneville Power Administration	2008	Renewable	USA	Roadmap by Bonneville for wind, wave, solar, and other renewable energies
19	Renewable energy technology roadmap	European Renewable Energy Council	2007	Renewable	EU	Roadmap for renewables in Europe until 2020
20	Renewable energy technology roadmap 20% by 2020	European Renewable Energy Council	2008	Renewable	EU	Roadmap for meeting 20% by 2020 European renewable energy targets
21	Research and development and demonstration roadmap	PIER Group	2007	Renewable	USA	Roadmap for public interest energy research program
22	Roadmap on regulations and standards for the electrification of cars	United Nations Economic Commission for Europe	2010	Transport	EU	Roadmap on regulations and standards for electric vehicles
23	Solar electric power	Photovoltaic Industry	2003	Photovoltaic	USA	Roadmap developed collaboratively by Photovoltaic Industry
24	Technology action plan: advanced vehicles	Major Economies Forum	2009	Transport	International	Roadmap of steps needed to promote advanced vehicle technology
25	Technology action plan: bioenergy	Major Economies Forum	2009	Biofuels	International	Roadmap for technology to extract energy from all forms of

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
						biological matter
26	Technology action plan: buildings sector	Major Economies Forum	2009	Built Envi-ronment	International	Roadmap for advanced building technology
27	Technology action plan: carbon capture, use, and storage	Major Economies Forum	2009	Carbon Cap-ture & Storage	International	Roadmap for carbon capture, use and storage technology
28	Technology action plan: high-efficiency, low emissions coal	Major Economies Forum	2009	Clean Coal	International	Roadmap for developing cleaner coal burning technologies
29	Technology action plan: industrial sector energy effi-ciency	Major Economies Forum	2009	Manufacturing	International	Roadmap for developing effi-cient technologies for industry e.g. manufacturing and logistics
30	Technology action plan: marine energy	Major Economies Forum	2009	Ocean Energy	International	Roadmap for developing wave, tidal, and tidal stream electricity generation
31	Technology action plan: smart grids	Major Economies Forum	2009	Energy Supply	International	Roadmap for developing smart electricity grids
32	Technology action plan: solar energy	Major Economies Forum	2009	Solar	International	Roadmap for developing solar energy through Photovoltaic and CSP
33	Technology action plan: wind energy	Major Economies Forum	2009	Wind	International	Roadmap for developing wind energy technology
34	Technology development roadmap	Cool Earth	2009	Renewable	Japan	Summary roadmaps for all low carbon technologies until 2050
35	Technology roadmap carbon capture and storage	International Energy Agency	2010	Carbon Cap-ture & Storage	International	Roadmap by IEA for carbon capture and storage until 2050
36	Technology roadmap concentrating solar power	International Energy Agency	2009	Solar	International	Roadmap by IEA on concentrat-ing solar power until 2050
37	Technology roadmap electric and plug-in hybrid electric vehicles	International Energy Agency	2009	Transport	International	Roadmap for electric and plug in hybrid vehicle technology

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
38	Technology roadmap for biofixation of CO_2 and greenhouse gas abatement with microalgae	US Department of Energy	2003	Carbon Capture & Storage	USA	Roadmap for micro algae use for capturing carbon dioxide
39	Technology roadmap for plant/crop based renewable resources 2020	Renewables Vision 2020	1998	Biofuels	USA	Roadmap for use of plant feedstock for chemical industry
40	Technology roadmap nuclear energy	International Energy Agency	2009	Nuclear	International	Roadmap for nuclear energy technology
41	Technology roadmap photovoltaic power	International Energy Agency	2009	Photovoltaic	International	Roadmap by IEA for photovoltaic power until 2050
42	Technology roadmap wind power	International Energy Agency	2009	Wind	International	Roadmap by IEA for wind power until 2050
44	Transmission technology roadmap	Bonneville Power Administration	2006	Energy Supply	USA	Roadmap by Bonneville for transmission technology
45	UKERC marine (wave and tidal current) renewable energy technology roadmap	UK Energy Research Centre	2009	Ocean Energy	UK	Roadmap for mobilizing wave and tidal power in the UK
46	Wind technology roadmap	Industry Canada	2009	Wind	Canada	Roadmap for Canada for wind energy technologies and solutions
47	Driving Transformation to Energy Efficient Buildings, Version 2.0	Johnson Controls et al.	2012	Built Environment	North America	Roadmap on policy for accelerating energy efficiency technology development
48	National Carbon Mapping and Infrastructure Plan - Australia	Carbon Storage Taskforce	2009	Carbon Capture & Storage	Australia	Roadmap for carbon capture & storage and pipeline infrastructure
49	National Low Emissions Coal Strategy	National Low Emissions Coal Council	2009	Carbon Capture & Storage	Australia	Roadmap for the carbon capture & storage and advice demonstrations
50	Refrigeration, air conditioning and foam blowing sectors technology roadmap	GIZ Proklima	2012	Built Environment	Germany	Roadmap for the built environment sector on alternative technologies
51	IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation	Intergovernmental Panel on Climate Change	2011	Renewable	International	Special Report by IPCC on renewable energy sources and

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
						climate change mitigation
53	Sustainable use of resources roadmap for Europe	European Steel Technology Platform	2009	Steel Industry	EU	Roadmap for sustainable use of resources in the steel industry
54	Technology Roadmap - Carbon Capture and Storage in Industrial Applications	International Energy Agency & United Nations Industrial Development Organization	2011	Carbon Capture & Storage	International	Roadmap for carbon capture & storage in industrial applications
55	Carbon Sequestration Leadership Forum Technology Roadmap	Carbon Sequestration Leadership Forum	2011	Carbon Capture & Storage	International	Roadmap for carbon sequestration
56	Carbon Sequestration Technology Roadmap	US Department of Energy	2007	Carbon Capture & Storage	USA	Roadmap for fossil energy use with carbon capture & storage
57	UK Carbon Capture & Storage Roadmap	UK Dept. of Energy & Climate Change	2012	Carbon Capture & Storage	UK	Roadmap on carbon capture & storage, UK
58	International Technology Roadmap for PV	Semiconductor Equipment and Materials International & PV Group	2012	Photovoltaic	International	Roadmap by industry for photovoltaic technology
59	China's Solar Future. A Recommended China PV Policy Roadmap 2.0	PV Group	2011	Photovoltaic	China	Roadmap for photovoltaic technology in China
61	Electric vehicles roadmap	Sustainable Energy Authority of Ireland	2011	Transport	Ireland	Roadmap for electric vehicle technology in Ireland
62	European Green Cars Initiative PPP	European Green Cars Initiative	2010	Transport	EU	Roadmap for electric and plug in hybrid vehicle technology in European Union
65	Distributed generation and cogeneration policy roadmap for California	California Energy Commission	2007	Energy	California	Roadmap for distributed generation and cogeneration
66	Materials Roadmap Enabling Low Carbon Energy Technologies	European Commission	2011	Energy	EU	Roadmap for materials in low carbon energy technologies
67	EU's white paper on transport	European Commission	2011	Transport	EU	Roadmap for a competitive and resource efficient transport

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
						system in Europe
68	CURC-EPRI Clean Coal Technology Roadmap	Coal Utilization Research Council & Electric Power Research Institute	2008	Carbon Capture & Storage	USA	Roadmap for clean coal technologies
69	Cleaner Power in India: Towards a Clean-Coal-Technology Roadmap (Discussion Paper)	Harvard University	2007	Carbon Capture & Storage	India	Roadmap for clean coal technologies in India
70	Technology Roadmap: Energy Efficient Equipment	International Energy Agency	2011	Built Environment	International	Roadmap for energy efficient heating and cooling technologies
71	Oak Ridge National Laboratory, R&D Roadmap for Water Heating Technologies	Oak Ridge National Laboratory	2011	Built Environment	International	Roadmap for water heating technologies
72	Building a roadmap for heat. 2050 scenarios and heat delivery in the UK	Surrey University & Imperial College London	2010	Energy	UK	Roadmap for heating technologies in UK
73	Power Tower Technology Roadmap and Cost Reduction Plan	Sandia Corp	2011	Energy	USA	Roadmap for concentrated solar power technology and cost reduction plan
74	Space Power and Energy Storage Roadmap	National Aeronautics and Space Administration	2011	Energy	USA	Roadmap for space power and energy storage technologies
75	Mapping & Gap Analysis of current European Smart Grids Projects	ERA-Net	2012	Energy	EU	Roadmap for smart grid technologies
76	The European Electricity Grid Initiative	European Network of Transmission System Operators for Electricity & European Distribution System Operators	2010	Energy	EU	Roadmap for electricity grid technologies
77	Strategic Technology Roadmap (Energy Field)	Ministry of Economy, Trade and Industry	2005	Energy	Japan	Roadmap for energy technologies in Japan
78	Rechargeable energy storage system onboard electric drive buses	US Dept. of Transport	2010	Transport	USA	Roadmap for rechargeable energy storage technologies for transport in USA

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
80	HyWays: The European Hydrogen Roadmap	European Commission	2008	Hydrogen	EU	Roadmap for hydrogen technology in Europe
81	Hydrogen Storage Technologies Roadmap	US Department of Energy	2005	Hydrogen	USA	Roadmap for hydrogen technology in USA
82	Hydrogen Production Roadmap	US Department of Energy	2009	Hydrogen	USA	Roadmap for hydrogen production technologies
83	Roadmap for Hydrogen and Fuel Cell Vehicles in California	University of California, Davis	2009	Hydrogen	USA	Roadmap for hydrogen technology for transport in USA
84	Roadmap on Manufacturing R&D for the Hydrogen Economy	US Department of Energy	2005	Hydrogen	USA	Roadmap for manufacturing technologies in hydrogen industry
85	Sustainable aviation fuel roadmap	Commonwealth Scientific and Industrial Research Organisation	2011	Aviation	Aus. & NZ	Roadmap for sustainable aviation in Australia and New Zealand
86	IATA Technology Roadmap	International Air Transport Association	2009	Aviation	International	Roadmap for aviation technology
88	Eurogas Roadmap 2050, The European Union of Natural Gas industry	Eurogas	2011	Natural Gas	EU	Roadmap for natural gas technology in Europe
89	Sustainable Aviation CO2 Road-map	Sustainable Aviation	2012	Aviation	UK	Roadmap for sustainable aviation in UK
91	National Algal Biofuels Technology Roadmap	US Department of Energy	2010	Biofuels	USA	Roadmap for algal biofuel technology
95	Northwest Energy Efficiency Technology Roadmap	Bonneville Power Administration	2011	Energy Efficiency	USA	Roadmap for energy efficiency technologies in Northwest USA
96	Technology Roadmap for Intelligent Buildings	Continental Automated Buildings Association	2002	Built Environment	Canada	Roadmap for intelligent buildings in Canada

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
97	High-performance commercial buildings: Technology roadmap	US Department of Energy	2001	Built Environment	USA	Roadmap for high performance commercial building technologies
98	Solid-state Lighting R&D Manufacturing Roadmap	US Department of Energy	2011	Lighting	USA	Roadmap for solid state lighting technologies
99	Future Road Vehicle Research, R&D Technology Roadmap	European Automotive Research Partners Association	2005	Transport	EU	Roadmap for future transport technologies
100	A Roadmap for 21st Century Chemical Engineering	UK Institution of Chemical Engineers	2007	Chemical	International	Roadmap for chemical engineering
101	Technology Roadmap for Environmentally Sustainable Food Manufacturing	Commonwealth Scientific and Industrial Research Organisation	2011	Food	Australia	Roadmap for sustainable food manufacturing
102	Roadmap 2050, Technical analysis	European Commission	2010	Technology	EU	Roadmap for a prosperous and low carbon Europe
104	Strategy and Road Map for Agricultural Science and Technology in Vietnam	Asian Development Bank	2003	Agriculture	Vietnam	Roadmap for agricultural technologies in Vietnam
107	Hydrogen Energy and Fuel Cells: A Vision of Our Future	European Commission	2003	Hydrogen	EU	Roadmap for hydrogen and fuel cell technology in Europe
108	The Icelandic Hydrogen Energy Roadmap	Icelandic Ministry of Industry and Commerce	2009	Hydrogen	Iceland	Roadmap for hydrogen energy technology in Iceland
109	UK Fuel Cell Development and Deployment Roadmap	Fuel Cells UK	2005	Hydrogen	UK	Roadmap for fuel cell technology in UK
111	UK Renewable Energy Roadmap	Department of Energy and Climate Change	2011	Renewable	UK	Roadmap for renewable energy technology in UK
112	Our future is carbon negative: A Carbon Capture & Storage roadmap for Romania	Bellona	2012	Carbon Capture & Storage	Romania	Roadmap by Bellona for carbon capture & storage in Romania
113	The Power of Choice - A Carbon Capture & Storage Roadmap for Hungary	Bellona	2012	Carbon Capture & Storage	Hungary	Roadmap by Bellona for carbon capture & storage in Hungary

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
114	Insuring Energy Independence: A Carbon Capture & Storage Roadmap for Poland	Bellona	2012	Carbon Capture & Storage	Poland	Roadmap by Bellona for carbon capture & storage in Poland
115	CSLF Strategic Plan, Second update, 2011-2016	Carbon Sequestration Leadership Forum	2011	Carbon Capture & Storage	International	Roadmap for carbon capture & storage technology
116	Technology Roadmap: Biofuels for Transport	International Energy Agency	2011	Biofuels	International	Roadmap for biofuels for transport technologies
117	A roadmap for carbon capture and storage in the UK	Clair Gough et al. International Journal of Greenhouse Gas Control	2010	Carbon Capture & Storage	UK	Roadmap for carbon capture & storage technology in UK
119	National Roadmap for Responding to Climate Change	USDA Forest Service	2010	Adaptation	USA	Roadmap for climate change adaptation by Forestry Department in USA
120	Exploring our Planet for the Benefit of Society	National Aeronautics and Space Administration	2005	Technology	International	Roadmap by NASA on applicable technologies
121	Electricity Technology Roadmap	Electric Power Research Institute (EPRI)	2003	Energy	International	Roadmap for electricity grid technologies
122	Implementation Of The Environmental Technologies Action Plan	Finnish Ministry of Trade and Industry	2005	Adaptation	Finland	Roadmap for adaptation technologies in Finland
123	Canadian Fuel Cell Commercialization Roadmap	Industry Canada	2003	Hydrogen	Canada	Roadmap for fuel cell technology in Canada
124	Canadian Fuel Cell Commercialization Roadmap Update: Joint Report of Hydrogen and Fuel Cells	Industry Canada	2008	Hydrogen	Canada	Roadmap for hydrogen and fuel cell technology in Canada
125	A Roadmap for a Secure, Low-Carbon Energy Economy	World Resources Institute & Centre for Strategic & International Studies	2009	Energy	International	Roadmap for low carbon energy technologies
126	Earth-Sun System Applied Sciences Program Coastal Management Program Element	National Aeronautics and Space Administration Science Mission Directorate	2005	Adaptation	USA	Roadmap by NASA on coastal adaptation technologies

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
127	Natural Gas Infrastructure Reliability	US Department of Ener-gy	2000	Natural Gas	USA	Roadmap for improving reliabil-ity of natural gas technology in USA
128	A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010	US Department of Ener-gy	2001	Nuclear	USA	Roadmap for deploying nuclear energy in USA
129	Solar photovoltaic electricity empowering the world	European Photovoltaic Industry Association & Greenpeace	2011	Photovoltaic	EU	Roadmap by Greenpeace and industry for photovoltaic tech-nology
130	Genomics GTL Roadmap	US Department of Ener-gy	2005	Energy	USA	Roadmap for harnessing bio-technological solutions for en-ergy in USA
131	Filling the Gap: Unconventional Gas Technology Roadmap	Petroleum Technology Alliance Canada	2006	Natural Gas	Canada	Roadmap for unconventional natural gas technology
132	Australian Geothermal Roadmap	Australian Government Department	2008	Geothermal	Australia	Roadmap for geothermal tech-nology in Australia
133	Marine Energy Technology Roadmap	UK Energy Research Centre	2010	Ocean Energy	UK	Roadmap for ocean energy technology in UK
134	Nuclear Fission Energy Roadmap	UK Energy Research Centre	2008	Nuclear	UK	Roadmap for nuclear fission technology
135	Accelerated Development of Fusion Power	United Kingdom Atomic Energy Authority	2005	Nuclear	UK	Roadmap for nuclear fusion technology
136	Tonga Energy Road Map 2010-2020	Tonga Government & International Renewable Energy Agency	2010	Energy	Tonga	Roadmap for reducing Tonga's vulnerability to oil shocks
137	Technology Roadmap: Bioenergy for Heat and Power	International Energy Agency	2012	Biofuels	International	Roadmap by IEA for bioenergy for heat and power
138	Technology Roadmap: Geothermal Energy	International Energy Agency	2011	Geothermal	International	Roadmap by IEA for geother-mal technology
139	Technology Roadmap: Smart Grids	International Energy Agency	2011	Energy	International	Roadmap by IEA for smart gird technology

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
140	Technology Roadmap: Solar Heating and Cooling	International Energy Agency	2012	Solar	International	Roadmap by IEA for solar heating and cooling
141	Strategic Research Agenda 2010 Agenda	European Biofuels Technology Platform	2010	Biofuels	EU	Roadmap for biofuel technology in Europe
142	Smart Grids	European Technology Platform	2010	Energy Supply	EU	Roadmap for electricity networks in Europe
143	Wind Energy: A Vision for Europe in 2030	European Wind Energy Technology Platform	2006	Wind	EU	Roadmap for wind power technology in Europe
144	Today's Actions for Tomorrow's PV Technology	Photovoltaic Technology Platform	2009	Photovoltaic	EU	Roadmap for photovoltaic technology in Europe
145	Zero Emission Fossil Fuel Power Plants (ZEP)	European Technology Platform	2006	Carbon Capture & Storage	EU	Roadmap for carbon capture & storage technology
146	Wind Energy Roadmap	Sustainable Energy Authority of Ireland	2011	Wind	Ireland	Roadmap by SEAI for wind power technology in Ireland
147	Smartgrid Roadmap	Sustainable Energy Authority of Ireland	2011	Energy Supply	Ireland	Roadmap by SEAI for smart grid technology in Ireland
148	BioEnergy Roadmap	Sustainable Energy Authority of Ireland	2010	Biofuels	Ireland	Roadmap by SEAI for biofuels technology in Ireland
149	Ocean Energy Roadmap	Sustainable Energy Authority of Ireland	2010	Ocean Energy	Ireland	Roadmap by SEAI for ocean energy technology in Ireland
150	Residential Energy Roadmap	Sustainable Energy Authority of Ireland	2010	Built Environment	Ireland	Roadmap by SEAI for built environment technology in Ireland
151	100% renewable electricity	PricewaterhouseCoopers	2010	Energy Supply	Europe	Roadmap by PWC for renewable energy systems in Europe
152	Biofixation of CO_2 and GHG Abatement with Microalgae	US Department of Energy	2003	Adaptation	USA	Roadmap for micro algae use for greenhouse gas abatement in USA

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
153	Reducing Air Pollution from Urban Transport	World Bank	2004	Transport	International	Roadmap for reducing air pollution from transport sector
154	Aluminium Industry Technology Roadmap	Aluminium Industry	2003	Industry	International	Roadmap for the aluminium industry
155	Canadian Geothermal Heat Pump Industry	Canadian Geoexchange Coalition	2012	Geothermal	Canada	Roadmap for geothermal technology in Canada
156	Australian Water Industry Roadmap	Water Industry	2005	Water	Australia	Roadmap for the water industry in Australia
157	TRM for Energy Reduction in Automotive Manufacturing	US Department of Energy	2008	Transport	USA	Roadmap for energy reduction in automotive sector in USA
158	Buildings CHP	US Department of Energy	2000	Energy Supply	USA	Roadmap for combined heat and power in the built environment in USA
159	Catalysis, Key to Sustainability	Dutch Ministry of Economic Affairs	2001	Chemical	Netherlands	Roadmap for chemical catalysis technology in Netherlands
160	National CHP Roadmap	United States Clean Heat & Power Association	2001	Energy Supply	USA	Roadmap for combined heat and power technology in USA
161	Clean Cities	US Department of Energy	2004	Energy	USA	Roadmap for clean energy technologies in the built environment in USA
162	European Concentrated Solar Thermal Road-Mapping	EcoStar	2003	Solar	Europe	Roadmap for concentrated solar thermal power in Europe
164	Desalination and Water Purification	US Department of Interior	2003	Water	USA	Roadmap for desalination and water purification in USA
165	Distributed Energy Resources	Electric Power Research Institute	2004	Energy Supply	USA	Roadmap for distributed energy technology in USA
179	Green Chemical Technology	Crystal Faraday Partnership	2004	Chemical	UK	Roadmap for sustainable chemical technology

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
180	Autogas in Europe, The Sustainable Alternative	European LPG Association	2009	LPG	Europe	Roadmap for liquefied petroleum gas technology in Europe
181	Malaria Vaccine Technology Roadmap	Malaria Vaccine Technology Roadmap	2006	Medical	International	Roadmap for malaria vaccine technology
182	Marine Hydrokinetic Renewable Energy	National Renewable Energy Laboratory	2010	Ocean Energy	USA	Roadmap for ocean energy technology in USA
183	Australian Desalination Research Roadmap	National Centre of Excellence in Desalination	2011	Water	Australia	Roadmap for desalination in Australia
186	Report of UK-China workshops on the Future of Energy Storage	Royal Academy of Engineering	2012	Energy Supply	UK	Roadmap for future energy storage technology
187	Philippine Water Supply Sector Roadmap	Philippine Water Sector	2008	Water	Philippines	Roadmap for water sector in Philippines
188	Water Sector Roadmap, Kingdom of Cambodia	Royal Government of Cambodia	2003	Water	Cambodia	Roadmap for water sector in Cambodia
189	Bangladesh Water Sector Review	Asian Development Bank	2003	Water	Bangladesh	Roadmap for water sector in Bangladesh
190	Water Sector Roadmap	Asian Development Bank	2003	Water	Pakistan	Roadmap for water sector in Pakistan
191	Water Sector Roadmap	Asian Development Bank	2003	Water	Vietnam	Roadmap for water sector in Vietnam
192	Replacing Coal with Wind Energy by 2020	Greenpeace	2006	Wind	China	Roadmap for wind power in Hong Kong

TRMs reviewed that do not directly relate to climate change mitigation and adaption technologies

No.	Technology Roadmap	Author	Year	Technology	Origin	Summary
996	International technology roadmap for semiconductors (ITRS) 2010 update overview	International Roadmap Committee	2010	Semiconductors	International	Regularly updated TRM for semiconductors, broad author team
997	The science ahead, The way to discovery; Particle Physics in the 21st Century	US DoE/NSF high-energy physics advisory panel	s.d.	High-energy physics	USA	Roadmap for high-energy physics in the US, long-term vision and actions
998	National electric delivery technologies roadmap; Transforming the Grid to Revolutionize Electric Power in North America	US DoE, Office of Electric Transmission and Distribution	2004	Power transmission Infrastructure	USA	Roadmap for power grid extension and related technologies
999	On track to 2040; Preparing the Australian rail supply industry for challenges and growth. Roadmap	Australian Rail Supply Industry	2012	Rail technologies	Australia	Roadmap for the AUS railway system for freight

Annex 2 - **Detailed Overview TRM Matrix**

MATRIX 0	International	Region			Country																				
		Australasia	EU	EU & NA	AUS	BGD	KHM	CAN	CHN	FIN	HUN	ISL	IND	IRL	JPN	NLD	PAK	PHL	POL	ROM	ESP	TON	GBR	USA	VNM
A1. Renewable energy technologies			2007, 2018-2022, IGO, CqT, AA 2007, 2018-2022, IGO, CqT, AA 2008, 2018-2022, IGO, CqT 2010, >2032, NGO, PD, SoS												2008, 2023-2032, GO, CqT 2006, >2032, GO, CqT, VR 2005, >2032, GO, PD, SoS, CqT, VR						2010, 2018-2022, Industry, CqT, AA	2010, not spec., GO	2011, not spec., GO	2011, 2023-2032, GO, CqT, AA, VR 2009, not spec., Academia	
A1.1. hydroelectricity	2011, >2032, IGO, AA																								
A1.2. wind energy	2009, not spec., IGO, AA 2009, >2032, IGO, CqT, AA, VR		2009, 2018-2022, IGO, PD, CqT, AA, VR, PfO 2011, 2018-2022, GO, CqT, AA, VR 2006, 2023-2032, Industry, CqT					2009, 2018-2022, Industry, PD, CqT, AA, VR						2011, >2032, GO, CqT, VR											
A1.3. biomass and bioenergy	2009, not spec., IGO, AA 2003, not spec., Academia, AA 2011, >2032, IGO, PD, SoS, CqT 2012, >2032, IGO, AA		2010, 2023-2032, Industry								2012, not spec., Industry			2010, >2032, GO, CqT, VR					2012, not spec., Industry	2012, not spec., Industry				2010, not spec., GO, PD, SoS 2005, not spec., GO	

A1.4. geothermal energy	2011, >2032, IGO, AA, VR, PfO				2008, not spec., GO, CqT, AA			2012, 2018-2022, Industry, PD, CqT, AA																	
A1.5. solar thermal electric energy	2009, not spec., IGO, AA 2009, >2032, IGO, CqT, AA, VR		2003, not spec., Industry, PD, CqT																					2011, 2018-2022, CqT, AA	
A1.6. solar photovoltaic energy	2009, >2032, IGO, SoS, CqT, AA, VR 2012, 2018-2022, Industry, CqT, AA, VR, PfO 2011, >2032, NGO		2009, 2018-2022, Industry, CqT, AA						2011, 2023-2032, GO, CqT, AA, VR						2009, >2032, GO, CqT, AA, VR 2009, >2032, AA, VR									2003, 2023-2032, Industry, PD, SoS, CqT, AA, VR	
A1.7. solar heating and cooling	2012, >2032, IGO, AA, VR																								
A1.8. marine energy (ocean, wave, tidal)	2009, not spec., IGO, AA													2010, >2032, GO, CqT, VR									2009, 2018-2022, Academia, PD, CqT, AA, VR, PfO 2010, 2023-2032, Industry, CqT, VR	2010, 2023-2032, Academia, PD, CqT, VR	

A2. Other energy-related technologies																									
A2.1. technologies supporting fuel switching from coal to gas			2011, >2032, Industry, PD					2006, not spec., Industry, PD, SoS																2000, not spec., GO, PD, SoS, CqT	
A2.2. use of hydrogen as a fuel			2003, >2032, IGO, SoS, CqT, VR		2008, <2018, GO, PD, SoS, CqT, AA, VR			2003, <2018, Industry, PD, SoS, CqT, AA, PfO 2008, 2023-2032, Industry, PD, SoS				2009, not spec., GO, SoS											2005, not spec., Industry, PD, SoS, CqT, AA	2002, not spec., GO, PD, SoS 2010, 2018-2022, GO, PD, SoS, CqT, AA, VR 2005, <2018, Industry, CqT 2009, <2018, Industry, PD, SoS, CqT, AA, PfO 2005, not spec., GO, PD, SoS 2003, >2032, Industry	
A2.3. advanced nuclear energy	2007, 2018-2022, Academia, CqT, VR 2002, >2032, GO, SoS, CqT, AA, VR 2009, >2032, IGO, CqT, AA, VR																						2008, >2032, Industry, VR 2005, >2032, Industry, VR	2001, <2018, GO	
A2.4. clean coal technologies	2009, not spec., IGO, AA 2008, 2023-2032, Industry, CqT, AA							2009, 2023-2032, GO, SoS, CqT, AA, VR					2007, not spec., Academia, AA												

A2.5 combined heat and power (CHP)														2011, >2032, GO, CqT, VR										2000, 2018-2022, Industry, PD, SoS, CqT, AA 2004, <2018, Industry, PD, SoS, CqT, VR	
A2.6. carbon capture and storage (CCS)	2009, not spec., IGO, AA 2010, >2032, IGO, CqT, AA, VR 2011, >2032, IGO, CqT, AA, VR 2011, 2023-2032, Industry, CqT, AA, VR 2011, <2018, IGO		2006, >2032, Industry		2009, 2023-2032, GO, AA 2009, 2023-2032, GO, CqT			2009, 2023-2032, GO, SoS, CqT, AA, VR															2012, 2023-2032, GO, AA, VR 2010, >2032, Academia, PD, SoS, VR	2000, 2018-2022, GO, CqT 2007, 2018-2022, GO, CqT, AA, VR	
A2.7. energy storage and distribution (including smart grids)	2009, >2032, IGO, CqT, AA 2011, >2032, IGO, AA, VR 2012, not spec., Industry, SoS		2012, 2018-2022, Industry, CqT, AA, VR 2010, 2018-2022, Industry, PD, SoS, CqT, AA, PfO 2010, >2032, Industry, SoS																						
A2.8. decentralized (distributed) energy systems (DES)																									

B. TRANSPORTATION	2004, not spec., IGO		2011, 2023-2032, GO, CqT, AA 2005, >2032, Industry, PD, CqT																					2004, 2018-2022, GO, CqT, PfO	
B1. improving drive train efficiency	2009, 2023-2032, PD, SoS																								
B2. supporting the use of alternative fuels	2009, not spec., IGO, AA 2009, >2032, IGO, CqT, AA, VR	2011, 2018-2022, Industry, SoS, AA	2010, not spec., GO, AA 2010, 2018-2022, Industry, CqT, AA, VR 2009, 2018-2022, Industry, CqT, AA											2011, >2032, GO, CqT, AA, VR										1998, 2023-2032, Industry, SoS, CqT, AA, VR	
B3. optimize transport operations																								2008, not spec., GO, SoS, CqT	
C. RESIDENTIAL AND COMMERCIAL BUILDINGS	2009, not spec., IGO, AA 2012, 2023-2032, Industry, SoS, AA							2002, not spec., Industry, PD, SoS						2010, >2032, GO, CqT, VR									2010, >2032, Academia, CqT, VR	2011, 2018-2022, Academia, PD, SoS, AA, VR 2001, 2018-2022, Industry, PD, SoS	
C1. heating, ventilation and air conditioning systems (HVAC)	2011, >2032, IGO, CqT, AA, VR																								
C2. building energy management systems (BEMS)																									
C3. high-efficiency electric lighting																								2011, <2018, Industry, SoS	

D. INDUSTRY	2009, not spec., IGO, AA																								
D1. iron, steel and non-ferrous metals			2009, <2018, Industry, CqT, AA																					2003, 2018-2022, Industry, SoS, CqT	
D2. chemicals and fertilizers																2001, <2018, Industry, PD, SoS, CqT, AA, VR							2007, <2018, Industry, PD, SoS, CqT, AA, VR 2004, 2023-2032, Industry, PD, SoS, CqT, AA, VR, PfO	2001, <2018, Industry, PD, SoS, CqT, VR	
D3. petroleum refining																									
D4. minerals																									
D5. pulp and paper																									
D6. food industry																									
D7. cement industry	2009, >2032, IGO, PD, CqT, AA																								
E. AGRICULTURE																									
E1. technologies for agriculture					2011, 2018-2022, Industry, PD, VR																				2003, not spec., IGO, PD, SoS, AA
F. WASTE MANAGEMENT																									
F1. technologies for waste management																									

G. ADAPTATION																								2010, not spec., GO, SoS	
G1.1 Coastal zones	2005, <2018, GO, PD, SoS, CqT, AA, VR, PfO																								
G1.2 Water resources					2005, not spec., Industry, PD, SoS, CqT 2011, not spec., Academia, PD, SoS, CqT, AA	2003, <2018, IGO, CqT, AA	?, <2018, Industry, CqT, AA										?, <2018, IGO, CqT, AA	2008, <2018, Industry, PfO						2003, 2018-2022, GO, PD, SoS, CqT, PfO	2003, <2018, IGO, CqT, AA
G1.3 Agriculture																									
G1.4 Public Health	2006, 2023-2032, NGO, SoS, CqT																								
G1.5 Infrastructure																									
H. GEOENGINEERING																									
H1. geoengineering technologies																								2003, not spec., Industry, PD, SoS	

Legend: each cell contains the detailed information of the TRMs found:

- **First: the publication year**
- **Second: the time horizon**
- **Third: the authoring organization (legend: see Chapter 5)**
- **Fourth: substantive elements present: PD: process description; SoS: Specification of stakeholders; CqT: Clear (quantified) targets; AA: Actions assigned; VR: Visual representation, PfU: Plan for update**

Table is complex and difficult to read. At request, an Excel file is available, including references of each TRM to the TRM numbers.

Annex 3 - **Detailed Matrices 1-6**

Matrix 1	**Geographical Source** **Interna-tional**	 **Annex I**	 **Non An-nex I**	**To-tal**
A1. Renewable energy technologies	12	39	4	55
A1.1. hydroelectricity	1	4		5
A1.2. wind energy	2	13		15
A1.3. biomass and bioenergy	5	14	2	21
A1.4. geothermal energy	2	6		8
A1.5. solar thermal electric energy	2	8		10
A1.6. solar photovoltaic energy	4	13	1	18
A1.7. solar heating and cooling	3	2		5
A1.8. marine energy (ocean, wave, tidal)	2	8		10
A2. Other energy-related technologies	6	53	5	64
A2.1. technologies supporting fuel switch coal → gas		4		4
A2.2. use of hydrogen as a fuel		14		14
A2.3. advanced nuclear energy		11		11
A2.4. clean coal technologies	2	2	1	5
A2.5 combined heat and power (CHP)		3		3
A2.6. carbon capture and storage (CCS)	3	16	2	21
A2.7. energy storage and distribution (incl. smart grids)	1	10	1	12
A2.8. decentralized (distributed) energy systems (DES)		4		4
B. TRANSPORTATION	6	29		35
B1. improving drive train efficiency	1	4		5
B2. supporting the use of alternative fuels	5	18		23
B3. optimize transport operations	1	1		2
C. RESIDENTIAL AND COMMERCIAL BUILDINGS	3	13		16
C1. heating, ventilation and air conditioning (HVAC)	2	4		6
C2. building energy management systems (BEMS)	1	3		4
C3. high-efficiency electric lighting	1	4		5
D. INDUSTRY	2	12		14
D1. iron, steel and non-ferrous metals		5		5
D2. chemicals and fertilizers		5		5
D3. petroleum refining		1		1
D4. minerals				0
D5. pulp and paper		1		1
D6. food industry				0
D7. cement industry	1	2		3
E. AGRICULTURE				
E1. technologies for agriculture		2	1	3
F. WASTE MANAGEMENT				
F1. technologies for waste management		1		1
G. ADAPTATION	1	5	5	11
G1.1 Coastal zones		1		1
G1.2 Water resources		3	5	8
G1.3 Agriculture				0
G1.4 Public Health	1			1
G1.5 Infrastructure				0
H. GEOENGINEERING				
H1. geoengineering technologies		1		1
Total	70	339	27	436

Matrix 2	Geographical Scope Interna-tional	 Re-gional	 Na-tional	 Lo-cal	To-tal
A1. Renewable energy technologies	15	11	27	3	56
A1.1. hydroelectricity	1	3		1	5
A1.2. wind energy	3	6	4	2	15
A1.3. biomass and bioenergy	5	7	8	1	21
A1.4. geothermal energy	2	3	3	1	9
A1.5. solar thermal electric energy	3	5	1	1	10
A1.6. solar photovoltaic energy	5	6	5	2	18
A1.7. solar heating and cooling	3	2			5
A1.8. marine energy (ocean, wave, tidal)	2	1	5	2	10
A2. Other energy-related technologies	13	10	38	4	65
A2.1. technologies supporting fuel switching from coal to gas		1	3		4
A2.2. use of hydrogen as a fuel		1	12	1	14
A2.3. advanced nuclear energy	3	2	6		11
A2.4. clean coal technologies	2		3		5
A2.5 combined heat and power (CHP)			3		3
A2.6. carbon capture and storage (CCS)	5	4	13		22
A2.7. energy storage and distribution (including smart grids)	3	6	2	1	12
A2.8. decentralized (distributed) energy systems (DES)			2	2	4
B. TRANSPORTATION	7	10	16	2	35
B1. improving drive train efficiency	1	1	3		5
B2. supporting the use of alternative fuels	6	6	9	2	23
B3. optimize transport operations	1		1		2
C. RESIDENTIAL AND COMMERCIAL BUILDINGS	3	1	10	2	16
C1. heating, ventilation and air conditioning systems (HVAC)	2		2	2	6
C2. building energy management systems (BEMS)	1		2	1	4
C3. high-efficiency electric lighting	1		3	1	5
D. INDUSTRY	3	2	8	1	14
D1. iron, steel and non-ferrous metals	1	1	3		5
D2. chemicals and fertilizers			5		5
D3. petroleum refining	1				1
D4. minerals					0
D5. pulp and paper			1		1
D6. food industry					0
D7. cement industry	2		1		3
E. AGRICULTURE					
E1. technologies for agriculture		1	2		3
F. WASTE MANAGEMENT					
F1. technologies for waste management		1			1
G. ADAPTATION	2		9		11
G1.1 Coastal zones	1				1
G1.2 Water resources			8		8
G1.3 Agriculture					0
G1.4 Public Health	1				1
G1.5 Infrastructure					0
H. GEOENGINEERING					
H1. geoengineering technologies			1		1
Total	98	91	219	32	440

Matrix 3	TRM Published date															
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
A1. Renewable energy technologies						3		2	3	3	5	14	10	10	7	57
A1.1. hydroelectricity										2	1		1	1		5
A1.2. wind energy								1	2	2	2	4	1	4		16
A1.3. biomass and bioenergy						1		2		2	1	2	5	4	4	21
A1.4. geothermal energy								1		2	2			3	1	9
A1.5. solar thermal electric energy						1				2	1	3		3		10
A1.6. solar photovoltaic energy						1		1		2	2	6	1	4	1	18
A1.7. solar heating and cooling										1	1	1		1	1	5
A1.8. marine energy (ocean, wave, tidal)										1	2	2	3	2		10
A2. Other energy-related technologies			3	1	2	3	1	6	5	3	5	14	8	7	6	64
A2.1. technologies supporting fuel switching from coal to gas			1					1	1					1		4
A2.2. use of hydrogen as a fuel					1	3		3			2	4	1			14
A2.3. advanced nuclear energy				1	1			3		1	1	3		1		11
A2.4. clean coal technologies											1	3				4
A2.5 combined heat and power (CHP)			1				1							1		3
A2.6. carbon capture and storage (CCS)			1					1	1	1		6	4	4	4	22
A2.7. energy storage and distribution (including smart grids)						1		1	1			2	3	2	2	12
A2.8. decentralized (distributed) energy systems (DES)						1	1		1	1						4
B. TRANSPORTATION	1				1	1	2	5	1	2	3	8	4	7		35
B1. improving drive train efficiency						1		1				2	1			5
B2. supporting the use of alternative fuels	1				1			2		2	1	7	3	6		23
B3. optimize transport operations											1	1				2
C. RESIDENTIAL AND COMMERCIAL BUILDINGS				1	1			1	2	1	1	2	3	3	1	16
C1. heating, ventilation and air conditioning systems (HVAC)					1				1	1		2		1		6
C2. building energy management systems (BEMS)					1							2		1		4
C3. high-efficiency electric lighting					1							2		2		5

D. INDUSTRY				2		1	1	2	1	1		4	1	1		14
D1. iron, steel and non-ferrous metals						1		1				2		1		5
D2. chemicals and fertilizers				2			1	1		1						5
D3. petroleum refining														1		1
D4. minerals																
D5. pulp and paper								1								1
D6. food industry																
D7. cement industry								1				1		1		3
E. AGRICULTURE																
E1. technologies for agriculture						1							1	1		3
F. WASTE MANAGEMENT																
F1. technologies for waste management													1			1
G. ADAPTATION						3		2	1		1		1	1		9
G1.1 Coastal zones								1								1
G1.2 Water resources						3		1			1			1		6
G1.3 Agriculture																
G1.4 Public Health									1							1
G1.5 Infrastructure																
H. GEOENGINEERING																
H1. geoengineering technologies						1										1
Total	2	0	6	7	10	26	7	41	21	31	34	97	52	75	27	436

Matrix 4	Time Horizon				
	<2018	2018-2022	2023-2032	2033-2050+	Total
A1. Renewable energy technologies	3	15	7	18	43
A1.1. hydroelectricity		3		2	5
A1.2. wind energy	1	7		5	13
A1.3. biomass and bioenergy	1	7		5	13
A1.4. geothermal energy		6		2	8
A1.5. solar thermal electric energy		6		3	9
A1.6. solar photovoltaic energy	1	7	3	5	16
A1.7. solar heating and cooling		2		2	4
A1.8. marine energy (ocean, wave, tidal)		3	1	2	6
A2. Other energy-related technologies	6	12	13	17	48
A2.1. technologies supporting fuel switch coal → gas	1	1	1		3
A2.2. use of hydrogen as a fuel	5			4	9
A2.3. advanced nuclear energy		4	1	5	10
A2.4. clean coal technologies			2	1	3
A2.5 combined heat and power (CHP)		1		1	2
A2.6. carbon capture and storage (CCS)		7	5	5	17
A2.7. energy storage and distribution (including smart grids)		5	2	3	10
A2.8. decentralized (distributed) energy systems (DES)		2			2
B. TRANSPORTATION	7	7	4	7	25
B1. improving drive train efficiency		1		2	3
B2. supporting the use of alternative fuels	5	5	2	5	17
B3. optimize transport operations		1			1
C. RESIDENTIAL AND COMMERCIAL BUILDINGS		5	2	4	11
C1. heating, ventilation and air conditioning systems (HVAC)		1		1	2
C2. building energy management systems (BEMS)				1	1
C3. high-efficiency electric lighting		1		1	2
D. INDUSTRY	4	4		4	12
D1. iron, steel and non-ferrous metals	1	1		2	4
D2. chemicals and fertilizers	2	2		1	5
D3. petroleum refining				1	1
D4. minerals					0
D5. pulp and paper		1			1
D6. food industry					0
D7. cement industry		1		2	3
E. AGRICULTURE					
E1. technologies for agriculture	1	1		1	3
F. WASTE MANAGEMENT					
F1. technologies for waste management		1			1
G. ADAPTATION	4	2	1	1	8
G1.1 Coastal zones					0
G1.2 Water resources	4	1	1		6
G1.3 Agriculture					0
G1.4 Public Health		1			1
G1.5 Infrastructure					0
H. GEOENGINEERING					
H1. geoengineering technologies				1	1
Total	46	124	45	114	329

Matrix 5	Authoring Organisation				
	IGO	GO	Acad.	NGO	In-dus.
A1. Renewable energy technologies	16	18	4	2	16
A1.1. hydroelectricity	3	1			1
A1.2. wind energy	6	6			3
A1.3. biomass and bioenergy	7	7	1	1	5
A1.4. geothermal energy	4	4			1
A1.5. solar thermal electric energy	6	2			1
A1.6. solar photovoltaic energy	6	6		1	6
A1.7. solar heating and cooling	5				
A1.8. marine energy (ocean, wave, tidal)	3	4	2		1
A2. Other energy-related technologies	10	25	5	1	23
A2.1. technologies supporting fuel switch coal →gas		2			2
A2.2. use of hydrogen as a fuel	1	5	1		6
A2.3. advanced nuclear energy	2	5	1		2
A2.4. clean coal technologies	1	1	1		1
A2.5 combined heat and power (CHP)		1			2
A2.6. carbon capture and storage (CCS)	5	9	1	1	5
A2.7. energy storage and distribution (incl. smart grids)	3	3			6
A2.8. decentralized (distributed) energy syst. (DES)		2			2
B. TRANSPORTATION					
B1. improving drive train efficiency	1	2			1
B2. supporting the use of alternative fuels	6	9	1		6
B3. optimize transport operations		1			
C. RESIDENTIAL AND COMMERCIAL BUILDINGS					
C1. heating, ventilation and air conditioning (HVAC)	2	1			2
C2. building energy management systems (BEMS)	1				2
C3. high-efficiency electric lighting	1				3
D. INDUSTRY					
D1. iron, steel and non-ferrous metals	1	1			2
D2. chemicals and fertilizers		1			4
D3. petroleum refining	1				
D4. minerals					
D5. pulp and paper		1			
D6. food industry					
D7. cement industry	2	1			
E. AGRICULTURE					
E1. technologies for agriculture	1			1	1
F. WASTE MANAGEMENT					
F1. technologies for waste management				1	
G. ADAPTATION	3	3	1	1	3
G1.1 Coastal zones		1			
G1.2 Water resources	3	1	1		3
G1.3 Agriculture					
G1.4 Public Health				1	
G1.5 Infrastructure					
H. GEOENGINEERING					
H1. geoengineering technologies					1
Total	100	123	19	10	111

Key:

IGO – International Governmental Organisation

GO – Governmental Organisation

Acad. – Academic Organisation

NGO – Non-Governmental Organisation

Indus. - Industry

Matrix 6	Substantive Elements					
	Pro-cess	Stake-holders	Tar-gets	Ac-tions	Vis-ual	Up-date
Average for all TRMs	**32%**	**36%**	**60%**	**54%**	**40%**	**9%**
A1. Renewable energy technologies	23%	14%	61%	55%	43%	9%
A1.1. hydroelectricity	20%	20%	80%	60%	40%	20%
A1.2. wind energy	33%	20%	73%	53%	53%	13%
A1.3. biomass and bioenergy	29%	24%	43%	38%	29%	10%
A1.4. geothermal energy	33%	22%	78%	78%	44%	22%
A1.5. solar thermal electric energy	30%	10%	80%	80%	40%	20%
A1.6. solar photovoltaic energy	28%	28%	72%	72%	61%	17%
A1.7. solar heating and cooling			40%	80%	20%	
A1.8. marine energy (ocean, wave, tidal)	40%	20%	60%	40%	50%	20%
A2. Other energy-related technologies	31%	40%	55%	46%	45%	6%
A2.1. technologies supporting fuel switching from coal to gas	100%	75%	50%		25%	
A2.2. use of hydrogen as a fuel	64%	79%	57%	43%	29%	14%
A2.3. advanced nuclear energy	18%	18%	55%	45%	82%	9%
A2.4. clean coal technologies		20%	40%	100%	40%	
A2.5 combined heat and power (CHP)	67%	67%	100%	33%	67%	
A2.6. carbon capture and storage (CCS)	23%	23%	50%	55%	55%	5%
A2.7. energy storage and distribution (including smart grids)	33%	42%	67%	58%	58%	17%
A2.8. decentralized (distributed) energy sys-tems (DES)	25%	50%	75%	50%	75%	
B. TRANSPORTATION	37%	49%	66%	51%	31%	9%
B1. improving drive train efficiency	60%	100%	60%	40%	40%	
B2. supporting the use of alternative fuels	39%	48%	61%	70%	35%	9%
B3. optimize transport operations	50%	100%	50%			
C. RESIDENTIAL AND COMMERCIAL BUILDINGS	44%	56%	44%	38%	56%	
C1. heating, ventilation and air conditioning systems (HVAC)	50%	50%	33%	67%	67%	
C2. building energy management systems (BEMS)	50%	50%		50%	50%	
C3. high-efficiency electric lighting	40%	60%		40%	40%	
D. INDUSTRY	64%	64%	71%	64%	57%	7%
D1. iron, steel and non-ferrous metals	20%	40%	80%	60%	60%	
D2. chemicals and fertilizers	100%	100%	100%	60%	100%	20%
D3. petroleum refining			100%	100%	100%	
D4. minerals						
D5. pulp and paper	100%	100%	100%		100%	
D6. food industry						
D7. cement industry	67%	33%	100%	67%	67%	

E. AGRICULTURE						
E1. technologies for agriculture	100%	67%		33%	33%	
F. WASTE MANAGEMENT						
F1. technologies for waste management	100%	100%				
G. ADAPTATION	36%	55%	82%	55%	9%	27%
G1.1 Coastal zones	100%	100%	100%	100%	100%	100%
G1.2 Water resources	38%	38%	88%	63%		25%
G1.3 Agriculture						
G1.4 Public Health		100%	100%			
G1.5 Infrastructure						
H. GEOENGINEERING						
H1. geoengineering technologies	100%	100%				

Annex 4 - **Short descriptions of the TRMs discussed in Section 6 on good practices**

Note: In our review, we did not find any 'perfect' TRMs: all of them can be improved in some respects. Therefore, none of these examples can be literally copied: our intention is to highlight particularly strong features of each TRM.

A4.1 **IEA Technology Roadmap on Wind energy**

120. The International Energy Agency has published some ten roadmap documents on key energy technologies since 2009. They essentially follow the same structure, and use the process guideline we already discussed in Section 5; here we discuss the wind energy TRM as a representative example.

Objective:

121. The roadmap aims to identify the primary tasks that must be addressed in order to reach the IEA vision for wind energy deployment. It also allocates these tasks to specific actors, in this case the wind energy industry, governments and power sector actors.

Methodology:

122. The methodology for preparing the TRM is not discussed in the document, but has been published in a separate report (IEA 2010) that we discussed in section 8.

Structure:

123. The TRM has the following structure:

1. *Wind energy today*, describing the wind power capacity growth in the past decades, and its economics
2. *Vision for deployment*, which discusses the foreseen future wind production capacity, projected cost reductions and the investments in wind power until 2050.
3. Four *Actions and Milestones* sections go into for actions and milestones related to:
   - Wind Technology Development and Deployment:
   - Delivery and System Integration
   - Policy Frameworks
   - International Collaboration
4. *Roadmap action plan and next steps,* in which the actions and milestones are allocated to specific actors, in this case the wind energy industry, governments and power sector.

A4.2 PV Group TRM for PV in China

Objective:

This document (PV Power et al 2011), produced by PV group, SEM and CPIA is an update of an earlier TRM on PV in China. Its objective is to provide a recommended

Roadmap for PV on the basis of more recent material on e.g. global solar-PV development.

Methodology:
The document does not provide detailed information about the methodology applied

Structure:
The structure is as follows:
1. In the *introduction* chapter, the IEA global outlook for PV is summarized, and it is discussed what role China plays in global energy development, that of PV in particular.
2. A *China PV industry overview* summarises the characteristics of the PV sector in China today, including seven key trends it is facing
3. The section *development of China's PV market and government incentive programs* focuses on future demand for PV in the Chinese domestic market, and how the government incentivises this
4. The *new recommended China PV policy roadmap* provides a target trajectory for the share of PV in Chinese power supply
5. The *policy recommendations* section finalizes the TRM

A4.3 Bonneville Power Administration TRM on energy efficiency technologies

Objective:
This TRM (Bonneville 2006) by regional governmental organization BonneVille Power Administration (BPA) mainly aims to streamline the R&D efforts of the organization itself. It provides road maps for seven energy efficiency technologies, such as efficient lighting and efficiency in industrial processes.

Methodology:
Main method for the TRM was literature study on e.g. key technology features, R&D challenges and R&D activities by other parties, and some quantitative assessment on technology potentials. Stakeholders were mainly used for the identification of technologies to focus on.

Structure:
The structure of each of the TRMs in this document is as follows.
1. A Technology overview describing essential elements of the technology
2. An *Opportunity overview*, describing which commercial opportunities
3. The *R&D challenges* section summarises the challenges that need to be overcome for the technology to reap the identified opportunities
4. *Sector actors* identifies which other parties are active in R&D on the technology, and what they focus on
5. The *Roadmap* summarises the findings so far, after which
6. The *Role for BPA* section identifies what role BPA could play, including concrete actions.

A4.4 SEAI TRM for Electric vehicles

Objective:
The TRM (SEAI 2005) aims to contribute to a strategic approach in which deployment of electric vehicles is integrated with the development of related technologies, such as intermittent renewable energy generation and smart grids.

Methodology:
For its scenarios, the TRM builds further on IEA work in this field; this is however not specified any further. The required activities were identified in consultation with stakeholders.

Structure:
The TRM contains:
1. An *introduction*, describing the challenges to the transport sector and the importance of electric vehicles to be deployed in an integrated manner
2. *Key findings* in terms of projected future market shares of electric vehicles, energy demand and relate (renewable) supply
3. A time-specific *EV deployment scenario*, including time-specific actions and the key parties responsible for them
4. Further detailed scenario *Key Results*.

A4.5 Fuel cells UK TRM for Fuel cell development and deployment

Objective:
This TRM (Fuel Cells UK 2005) is a follow-up of the 'Fuel Cell Vision for the UK', published by Fuel Cells UK in 2003. This Vision highlighted the benefits to the UK in taking a leading role in fuel cell (FC) development and deployment. The purpose of this Roadmap is to accelerate the commercialisation of fuel cell technologies within the UK, and to ensure that the UK derives maximum benefit from that process. It aims to specify routes and milestones for all stakeholders, including government, industry and society at large.

Methodology:
The methodology is not discussed in full detail, but the development of this TRM involved an extensive process of consultation. The UK fuel cell community put substantial effort into the work, estimated at almost 500 hours committed.

Structure:
The TRM has the following structure:
1. An *introduction*, in which the reasons for fuel cells, their commercial potential and the objectives of the TRM are specified
2. An extensive *review of FC activities* in the UK, in industry, research, government and other sectors, and a discussion of the position of the UK in the global context
3. An identification of *UK FC strengths*
4. A *UK FC Focus* chapter proposing areas to concentrate activities on
5. The *UK FC Challenges, strategies and actions* chapter is the most comprehensive
6. A *recommendations* chapter.

A4.6 Crystal Faraday Partnership TRM on Green Chemical Technology

Objective:
This TRM (Crystal Faraday Partnership 2004) aimed to develop a strategy for green chemical technology research and development based on the future needs of industry, with a 2025 time horizon. The technology strategy provides key decision-makers in industry, academia and the government with a picture of the role that green chemical

technology can play in developing a vibrant and sustainable chemical industry in the UK. It identifies the opportunities, gaps and key actions that need to be taken to make sure that the potential of green chemical technology is delivered.

Methodology
This TRM used an elaborate method, starting with an identification of basic (societal, technical, environmental and other) trends and drivers, linking them to consequent future requirements to chemical products and processes, identifying technology characteristics, and ending with key R&D challenges and corresponding gaps in current R&D. See also Figure 5. The strength of such an outside-in approach is that it contributes to the societal relevance and value added of a TRM.

Structure:
The TRM has the following structure:
1. An *introduction*, with an introductory overview of the chemical sector and the TRM objectives
2. A *Development of the Roadmap* section, describing the methodology applied for the TRM
3. A review of *Trends and Drivers* that affect the future of the chemical industry, describing trends in social, technology, economic, environmental and political areas. Trends are summarized in Vision statements
4. In the section *Features, Attributes and Technology Impact*, the vision is translated in to goals, and then into required sector features, attributes and the technology areas that are related to them
5. The *Technology Roadmaps* section describes for the different technology areas which barriers and dependencies exist
6. It concludes with *Priority Activity areas.*

A4.7 Asian Development Bank TRM on Water in Viet Nam

Objective:
The objective of this TRM (ADB 2003) is to contribute to the country's Comprehensive Poverty Reduction and Growth Strategy. This strategy aims to (i) increased income in the rural sector, (ii) reduce income disparities, risks and vulnerability, and improved food security and social well-being of the poor, and (iii) improve sustainability of natural resources in rural areas. Water plays an important role in meeting these goals, and the TRM goes into issues on (a) water resource management, (b) irrigation services, and (c) water supply & sanitation.

Methodology:
The report does not contain any information on the methodology followed to come to the TRM.

Structure:
After an introductory background chapter, the core of the TRM is a table set that structures:
1. *Sector Outcomes*, specified for points a-c above, with indications of the developments in the past 5 years, the current situation, and indicators for success in 5 and 10 years.
2. A S*ector Outputs* table, in which the desired outcomes are transferred in more practical ambitions.
3. An *Issues and Constraints* table, discussing regulatory, institutional, infrastructural and other barriers.

4. An *Actions, Milestones and Investments* table, including a time schedule and an identification of the role of ADB and other parties.

A4.8 International Technology Roadmap for Semiconductors (ITRS)

Objective:

As a whole, the semiconductor industry aims to continue the rapid improvements in semiconductor products that have led to the frequently cited Moore's Law, whilst simultaneously decreasing the costs per function of their products.

The most significant objective of the ITRS itself is industry collaboration. The improvement trends are enabled by large R&D investments, which require industrial collaboration.

As a result of this collaboration, the ITRS has improved the quality of R&D investment decisions made at all levels and successfully channelled research efforts to areas that most need research breakthroughs.

Methodology:

The development of the ITRS is a dynamic process, with participation from semiconductor experts from EU, Japan, Korea, Taiwan, and the US. Experts meet in workshops to identify trends and challenges in specific technology areas, before a committee brings all these together to form an industry wide roadmap.

Structure:

The ITRS is well laid out with an introductory section contains a summary of the key findings, and the roadmap itself. The findings of each of the 15 technology workgroups are then presented.

A4.9 TRM on Power Grids

Objective:

Years of under-investment in the electricity grid contributed to the 2003 blackout that affected 50 million people in the Great Lakes region of USA. Modernizing the grid became a national priority. Recognising that neither the government nor the industry could act along, a roadmap was created as a framework to bring together all the stakeholders involved in the electric industry to work towards common aims.

Methodology

The US Department of Energy convened a series of two day workshops bringing together over 250 industry professional to generate an 'action agenda'. The first workshop brought together senior executives and policy makers to develop a 'vision' of the future. The aim of a second workshop attended by technical experts was on building a consensus on how to achieve the vision.

Structure

The introduction makes a clear explanation of the roadmapping concept, and describing its context and aims. The roadmap is presented at the start of the document, before the action items are developed in subsequent chapters. The appendices list out the participants and a useful summary of the short term RD&D needs.