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Technology roadmaps: An evaluation of their success in the renewable energy sector

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ABSTRACT

Strategy literature has highlighted success factors for technology roadmaps (TRMs). However, as roadmaps have evolved – from traditional, single organisation roadmaps, towards multiple organisation, sector level roadmaps – their objectives and success criteria have also changed. This paper develops a set of roadmap evaluation metrics, firmly focussed on evaluating the level of success of a roadmap based on whether its objectives have been translated into actions or policies by the target organisation, and uses them to analyse four renewable energy roadmaps to determine the success factors for developing a contemporary multi-organisation roadmap.

The analysis revealed a number of success factors distinctly different from those for traditional roadmaps. The study concludes that, alongside the traditional TRM, a new type of roadmap has emerged, whose principal aim is political persuasion. These roadmaps are written by multiple organisations, often at the sector level, to persuade governments that they should implement the actions and recommendations set out. As a result of the emergence of this new type of roadmap, new metrics and guidance are required for roadmap construction compared to traditional roadmaps.

1. Introduction

This paper is focussed on how technology roadmaps (TRMs) have evolved. Acknowledging that multi-organisation TRMs (where consortia of organisations come together to collectively develop a TRM) are fundamentally different from traditional TRMs (developed by a single organisation for the benefit of that same organisation), it develops a set of metrics for measuring the level of success of a contemporary multi-organisation roadmap. Driven by the nature of the evolution of TRMs, these metrics developed are firmly focussed on evaluating the level of success of a roadmap based on whether its objectives have been translated into actions or policies by the target organisation. These metrics are then used to evaluate four TRMs from the renewable energy sector and, based on this analysis, the paper identifies the key success factors for multi-organisation TRMs and provides recommendations for the development of a successful multi-organisation roadmap. The conclusion of the paper reflects on the key features of multi-organisation roadmaps that have been revealed and how they differ from traditional roadmaps.

This work contributes significantly to the body of literature available on the TRM process. Whilst over the past ten years there has been a large increase in the amount of literature available on TRMs, there is only a limited amount of information available on the success factors and barriers to success for TRMs, and on how TRMs have evolved. The limited information available on success factors is principally aimed at traditional TRMs. Whilst traditional success factors are still relevant – and traditional, single organisation TRMs are still a widely used and effective strategic planning tool – little work has been done to investigate how the success factors have changed as roadmaps have evolved and their objectives and purpose have changed — the principal focus of this paper.

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The remaining parts of this introduction will introduce the concept of technology roadmapping and present the key features of traditional TRMs, before focussing on how the TRM process has been adapted and evolved since it was first developed and applied.

1.1. What is technology roadmapping and why is it important?

Technology roadmapping is a strategic tool that can be used by many different organisations to integrate science and technology with business and product planning as a means to achieve a desired set of objectives [1,2]. TRMs are developed as a medium to long term action plan to forecast the direction of future markets and developments in technology and help make strategic decisions [1], providing a critical link between technology investment decisions and business planning [3] and providing a structured approach for mapping the evolution and development of complex systems [4].

It is often considered that the process of developing a roadmap is as important as the document itself, as it requires stakeholders to form relationships and work together to develop a plan to achieve common goals and objectives [5].

An effective roadmap must address three key questions: (i) Where do we want to go? i.e. what are the objectives that the roadmap will assist in achieving, (ii) Where are we now? i.e. what is the current level of technology development, is there currently a market in place etc., and (iii) How can we get there? i.e. what technology R&D is required, what policies need to be implemented etc. [5].

Nimmo [6] describes the positive effects of developing a TRM: "TRM helps predict technologies that will be imperative to addressing future markets, charting a strategic pathway for commercialising right technologies, guiding industry to making the most out of new market opportunities, steering the direction of R&D decisions, building new partnerships and providing decisive input to government policy". TRMs can be applied to all sectors and types of technology and act as an efficient communication tool that makes the end objectives and the route to achieving those objectives clear to all involved. As a result, there has been significant increase in the use of the TRM method during the period 2000–2010 throughout the world [1] as companies, organisations, consortia and governments have utilised the method to address a diverse range of issues across a diverse range of industry sectors.

1.2. Traditional TRMs

Since the first fully traceable TRM was produced by Motorola in the 1970s, the concept has been used by many organisations, industries and countries as an effective strategic planning tool for all types of technologies. TRMs can be implemented by almost any technology, but the approach must be tailored to the focus and scope of the issue being addressed [5].

Traditional TRMs are written by a company or organisation, for the benefit of that same organisation. For example, an organisation might develop a roadmap to provide a critical development path of the future for a product, integrating relevant strategic information such as technologies, products and markets. This kind of organisational TRM is used as an information and strategic planning tool to allow the organisation to make the best possible decisions relative to the product in question [7]. There are three important characteristics of traditional, organisational TRMs:

1. The author is a single organisation.
2. The intended audience of the TRM is the same organisation.
3. The purpose of the TRM is to act as a strategic planning tool.

1.3. Evolution of technology roadmaps

Between the 1970s and the time of writing, TRMs have significantly evolved as the process has been used by different types of organisation, for different sectors, different purposes and different audiences. Who develops a TRM, its purpose and intended audience all have a significant impact on the form of the roadmap and its objectives and drivers [1].

The realisation that there are large benefits to enlarging the scope of the TRM process from single organisations to consortia of organisations and even entire industrial sectors [8,9] has been a major driver of the evolution of TRMs. Important benefits of developing TRMs across industry sectors and across diverse stakeholders such as academia and industry include promoting collaboration and knowledge exchange, forging durable networks, and more efficient usage of scarce funds [10]. The distinction between 'traditional TRMs' and 'multi-organisation TRMs' which is used throughout this paper and is distinctive of the evolution of TRMs is in alignment with Phaal et al. [11] who make the distinction between the TRM approach applied at 'firm' level and 'sector' level. A further key feature of many contemporary multi-organisation TRMs is also that the target audience is a different organisation from the organisations which come together to develop the roadmap.

It is important to highlight that, whilst new types of TRM have emerged in addition to traditional TRMs as the TRM process has evolved and been applied by different organisations and with different purposes, traditional single organisation TRMs are still widely used as an effective strategic planning tool by many organisations worldwide.

The evolution of multi-organisation TRMs in addition to traditional, single organisation TRMs means that their objectives and drivers have also evolved. The research hypothesis tested in this research is that, as a result of the evolution discussed, the success factors for multi-organisation TRMs are different from those for traditional TRMs and new metrics for the evaluation of the level of

success of TRMs are required. This research hypothesis is tested throughout the analysis conducted and is reflected upon in Section 6.

2. An overview of TRMs in the wind and marine renewable sector

In the decade leading up to 2012, decarbonisation and energy security have both increasingly become energy policy priorities in the UK and internationally [12–14]. These issues, coupled with ambitious targets such as those set out in the EU Directive on Renewable Energy [15], present an important driver for developing renewable energy technologies such as wind and marine (wave and tidal current) energy technologies. As a result, both sectors have seen a large uptake of the roadmapping process in the decade leading up to 2012.

The following sections present an introduction to TRMs in the wind and marine renewable energy sectors which are the focus of the four roadmaps analysed in this paper. A brief overview of the wind and marine energy sectors is presented in the following two sections respectively, followed by a brief justification of why the two sectors are suitable case studies of multi-organisation roadmaps.

2.1. Overview of the wind sector

In this paper, both onshore and offshore wind are considered in the scope of the wind sector, both of which are more mature than the marine energy sector.

There has been a huge growth in the wind energy sector especially in the decade up to 2012. It is estimated that installed capacity reached 84.3 GW across the EU at the end of 2010 with 9.3 GW installed in 2010 alone [16]. The already large number of people employed in the EU by the wind industry is forecast to increase as the sector plays a large role in meeting decarbonisation and renewable deployment targets. EWEA [17] highlights that on aggregate, the National Renewable Energy Action Plans (NREAPs) of the EU member states indicate that wind energy installed capacity will be 213 GW in 2020, and that this will supply 14% of Europe's total electricity demand. Wind energy is one of the most developed renewable sources of energy today, and there is thus a large pressure on the industry to become an increasingly major contributor to the energy mix and play a large role in mitigating climate change and providing energy security.

2.2. Overview of the marine energy sector

In this paper, marine energy is defined to include wave and tidal current energy. Both wave motions and flows of large volumes of water in tidal streams present a large store of kinetic energy which can be used by wave and tidal stream technologies respectively to generate electricity.

Despite the fact that design consensus has not been achieved and there are multiple design concepts in development for both the wave and tidal current sectors, in the period up to 2012 there has been a renewed high interest in the development of marine energy systems (which have received significant policy interest and financial support), and now the first generation of economically viable technologies is close to market [18].

Growing international interest has seen the establishment of various frameworks (such as the IEA Ocean Energy Systems Implementing agreement [19]) for international collaboration in the sector. A number of marine energy test centres (such as the full-scale test centre at the European Marine Energy Centre (EMEC) in Orkney) have also now been established. However, it is important to note that there are still many barriers to the development of the sector, despite the fact that over a dozen countries now have support policies for marine energy. Much of the development of the sector to date has been based in the UK, and marine energy technologies are still very much emerging with high associated costs and uncertainties.

In comparison to the NREAP projections for wind energy of 213 GW installed capacity in 2020, supplying 14% of Europe's total electricity demand, the EU Member States NREAP projections on aggregate indicate that the installed capacity of marine energy in 2020 will be 2.5 GW, supplying approximately 0.15% of the total EU electricity consumption [20].

2.3. Justifications for the use of the wind and marine energy sectors for a case study analysis focussed on multi-organisation TRMs

A 2010 study [1] found that the energy sector is the single sector with the highest number of public domain roadmaps, and that nearly 40% of these energy sector roadmaps were devoted to sustainable energy technologies such as wind and marine energy technologies.

TRMs present a method for bringing a number of interested parties together to develop a pathway to deploying renewable technologies, and ultimately, to achieving their commercialisation [21]. The challenges which face the wind and marine energy sectors would be impossible to overcome by any single organisation, and therefore the TRM process, bringing stakeholders together, has significant benefits.

There is a significant commitment to developing the sectors to realise the benefits they present in terms of emission reductions, increased energy security and economic benefits such as job creation. Both of the sectors are very pertinent and current, and require commitment and engagement from a large range of stakeholders in order to facilitate successful developments and deployments. These factors mean that the sectors lend themselves well to the TRM approach, and have led to a

large number of roadmaps being written within the two sectors in recent years, justifying why the sectors have been chosen for the case study analysis.

The detailed case study of the wind and marine energy sectors will allow the investigation of the success factors for contemporary multi-organisation TRMs in these two related and emerging sectors. Whilst care needs to be taken in extrapolating these results to other sectors, outside the scope of the case study, the success factors indicated and revealed are likely to be applicable to TRMs in other sectors, both within the renewable and wider energy sector, and beyond.

3. Evaluating the success level of a TRM

This section presents a review of the academic literature which exists on evaluating the level of a success of a TRM, which is almost exclusively focussed on traditional TRMs. This is then built upon in the following section where a new set of nine metrics to evaluate the level of success of a multi-organisation TRM is developed and used to analyse the four case study roadmaps from the wind and marine energy sectors.

3.1. TRM success factors and barriers to success

As highlighted above, over the last ten years there has been a significant increase in the amount of literature available on TRMs, however there is still a limited amount of information available on the success factors and barriers to success. Applying the definition of a critical success factor for a company or organisation [22], the success factors for a TRM are defined as the limited number of key characteristics, variables or areas that can have a significant impact on the overall success of a TRM. The limited information available on success drivers is principally aimed at traditional, single organisation technology roadmaps. Whilst traditional success factors are still relevant, little work has been done to investigate how the success factors have changed as roadmaps have evolved and their objectives and purpose have changed.

A study by Phaal et al. [23] identified some important traditional TRM success factors and barriers to success, shown in Fig. 1.

Phaal et al. [23] identified the main challenges as: keeping the TRM process “alive” on an ongoing basis, initiating the TRM process and developing a robust TRM process. Since the Phaal et al. [23] report identifying the success factors and barriers to success, there have been many publications, websites (such as www.technologyroadmapping.com) and software tools to help companies implement the TRM process.

Da Costa et al. [7] state that “the main characteristics of successful roadmaps are their clarity with the focus put on the information displayed in the graphics, their synthetic view and their relevance to allow decision makers to concentrate on what is strategic for the decisions to be taken rather than being diverted by excessive detail”.

Gerdsri et al. [24] highlight some of the key measures for success during the 3 stages of TRM implementation, shown in Fig. 2.

4. Methodology

This section is constituted of two distinct parts. In the first, a set of nine evaluation metrics is developed, focussed on evaluating the level of success of a multi-organisation TRM. The second then sets out how these nine metrics are then used to critically analyse and compare four multi-organisation roadmaps from the renewable energy sector in a case study analysis.

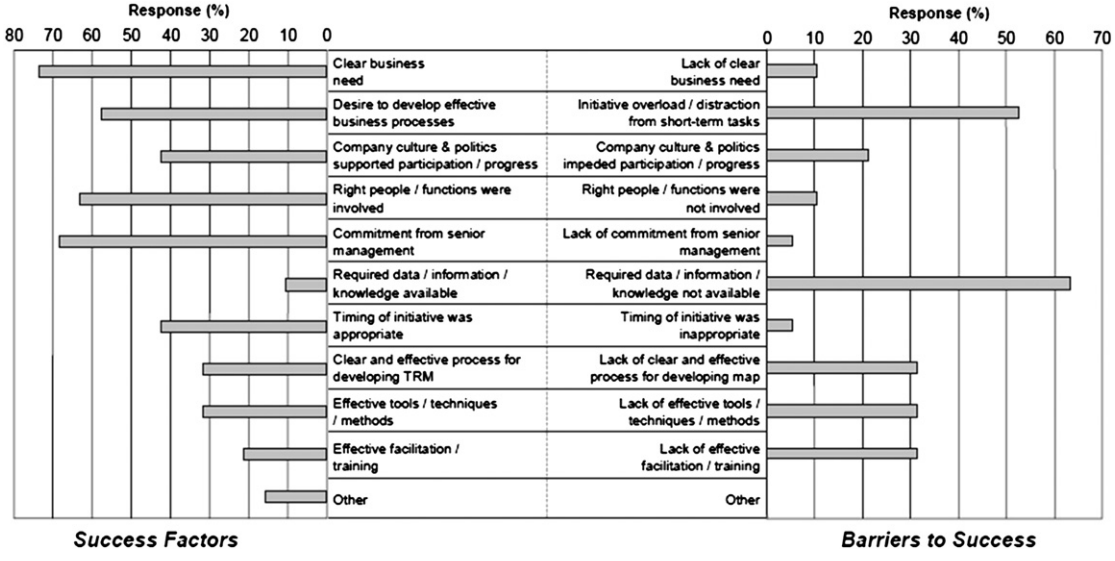

Fig. 1. TRM success factors and barriers to success [23].

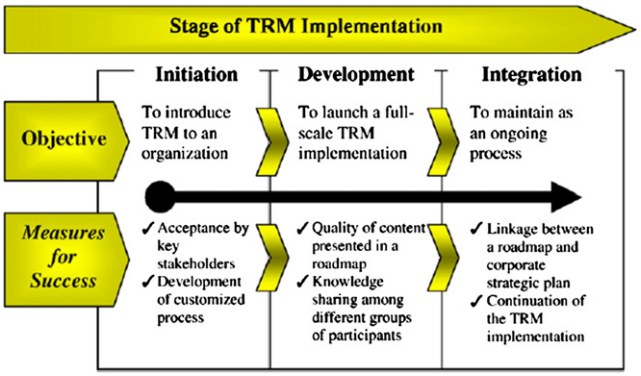

Fig. 2. TRM objectives and measures for success [24].

4.1. Developing a set of evaluation metrics to evaluate the level of success of a multi-organisation TRM

The limited amount of previous analysis on the success factors and barriers to success for traditional TRMs does not take account of the evolution of TRMs discussed in the previous sections. This paper builds on the work which has already been done on success factors and barriers for traditional TRMs and develops a set of metrics for evaluating the level of success of a multi-organisation TRM.

Developing the acknowledgement by Industry Canada [9] that the success of a TRM should be based on how well it is achieving its intended results, the set of metrics developed is firmly based on evaluating the level of success of a TRM based on whether its objectives have been translated into actions or policies by the target organisation. This builds directly upon the work of Da Costa et al. [7] who identified that the ultimate evaluation of a foresight study such as a TRM is whether the outcomes have been translated into actions and have triggered changes within the target organisations.

This paper developed a bespoke set of metrics to obtain comparative data. The set of nine metrics developed (specifically focussed on evaluating the level of success of a multi-organisation TRM) is shown in Table 1. The first five metrics are principally traditional success factors, developed in close alignment with those presented in the existing academic literature. However, metrics six to nine are firmly focussed on evaluating the level of success of a TRM based on whether it has achieved its objectives by assessing:

1. The TRM's uptake; and
2. Whether its objectives have been translated into actions or policies by the target organisation.

In this vein, metric seven is focussed on assessing the level of uptake of the TRM based on citations and references, whilst metrics six, eight and nine are focussed on evaluating the level at which the TRM's recommendations have been implemented or are in the process of being implemented, across three key areas: policies, technology, and supply chain.

It is important to note that there is a time dimension inherent in the above metrics. Using the metrics developed to analyse a roadmap's success, metrics six to nine (which are devoted to assessing the impact of the roadmap) will be more significant as time passes as they represent the results of the roadmap and whether or not its objectives have been achieved.

Table 1
Nine metrics to critically assess the success level of a multi-organisation TRM.

Type	Metric	How metric is assessed
Metrics assessing the architecture of the TRM and how it was prepared.	1. Author	Scored depending on the reputation of the author and who they selected to be a part of the TRM process (this is a traditional success factor for compiling a roadmap).
	2. Target audience	Scored based on how well the roadmap addresses its entire target audience.
	3. Roadmap message, effectiveness of delivery	Analyses a roadmap's message and how well it is delivered, taking into account format consistency and language.
	4. Are the stakeholders adequately addressed?	Measures how well, and how evenly, the stakeholders relevant to the roadmap are addressed.
	5. Ease of use — method used	Measures how easy to follow the roadmap is for readers from a range of backgrounds.
Metrics assessing the results of the TRM and whether it has achieved its objectives.	6. Status of suggested policies	Scored based on whether the roadmap's suggested policies have been implemented or are in the process of being implemented.
	7. Citations and references	Scored based on the number of times the roadmap has been cited (highest weighting for citations by another roadmap or by government).
	8. Technology	Scored based on whether the roadmap's technology recommendations have been, or are in the process of being developed.
	9. Supply chain	Scored based on whether the roadmap's supply chain recommendations have been or are in the process of being implemented.

4.2. Case study analysis of 4 roadmaps within the renewable energy sector

As discussed above, the case study analysis in this paper is focussed on two sectors within the wider renewable energy sector which have been the subject of a large number of TRMs in the period up to 2012: the wind sector, and the marine energy sector. The nine metrics developed were used to critically analyse and compare four multi-organisation roadmaps from the two sectors. This analysis will facilitate the identification of success drivers for multi-organisation TRMs and is built upon in Section 6 which develops a set of recommended guidelines for implementing a successful roadmap.

The four roadmaps selected for the analysis, all of which are multi-organisation, sector level roadmaps, are presented in Table 2. The roadmaps were selected to allow the comparison of roadmaps from the same sector as well as between two different sectors, and to facilitate the comparison of roadmaps written by different types of authors from industry, research and government.

Each of the four TRMs was critically assessed and given a score from one (low) to ten (high) for each of the nine metrics developed in the previous section. The results of the analysis are presented and discussed in the following section.

5. Case study analysis and discussion

The results of the case study analysis of four TRMs within the renewable energy sector are presented graphically in Fig. 3 and then discussed in further detail.

The following subsections focus on each of the nine metrics respectively, analysing how the four roadmaps were evaluated against each metric and presenting some examples of the underpinning factors responsible. It is important to highlight that there is some inherent subjectivity in the evaluation and scoring of the four TRMs against the metrics. For example, for the second metric, the TRMs are given a score based on the authors' judgement of how evenly and effectively they address their full target audiences, based on a comprehensive evaluation of the evidence available. In addition to this, in the interests of space, a detailed and comprehensive justification of the score awarded to each of the four TRMs against each of the nine metrics is not included. For example, for the 6th metric, status of suggested policies, a list of all the policy recommendations of each TRM, accompanied by policy developments which have been either in alignment or otherwise with these recommendations is not included. Rather, each of the four TRMs is given a score against the metric, and these are then discussed with some pertinent examples of the underpinning factors responsible for each score.

For the final four metrics (which are focussed on evaluating the success of each TRM based on its uptake and whether its objectives have been translated into actions or policies by the target organisation), it is important to highlight that causality is not necessarily implied between the recommendations made by a TRM and policy developments by the target organisations in alignment with their recommendations. For example, there have been a number of supply chain developments in line with the recommendations of the MEG roadmap, yet these developments were not necessarily a direct result of the roadmap's recommendations. Rather, the fact that there have been policy developments in direct alignment with the roadmap's recommendations is taken as an indication of the quality of those recommendations and their success level.

5.1. Author

The UKERC, MEG and IEA roadmaps all have authors with strong reputations and include input from a wide range of stakeholders. Of the three roadmaps, the IEA roadmap was scored the highest due to the international extent of its reputation across the entire energy sector and the fact that it was compiled with input from a very wide range of internationally renowned stakeholders (from academia, government, finance and the wind industry itself).

In comparison to the other three, the EWEA roadmap received a low score against this metric. This is due to the fact that, despite having an author with a high reputation (EWEA is constituted of 650 members, predominantly from industry and represents 90% of the global wind power market), the roadmap is limited to input from industry. The roadmap fails to take account of important stakeholders such as governments and academia and this restricted range of input detracts from its effectiveness.

Table 2
The four TRMs analysed in this paper.

Sector:	Roadmap:	Author type:
Marine energy	UKERC Marine Renewable Energy Technology Roadmap [25]	Research
	Forum for Renewable Energy Development in Scotland's (FREDS) Marine Energy Group's (MEG): Marine Energy Roadmap [26]	Government and industry
Wind energy	International Energy Agency (IEA) Technology Roadmap: Wind Energy [21]	Government, research and industry
	European Wind Energy Association (EWEA) oceans of opportunity: harnessing Europe's largest domestic energy resource [27]	Industry

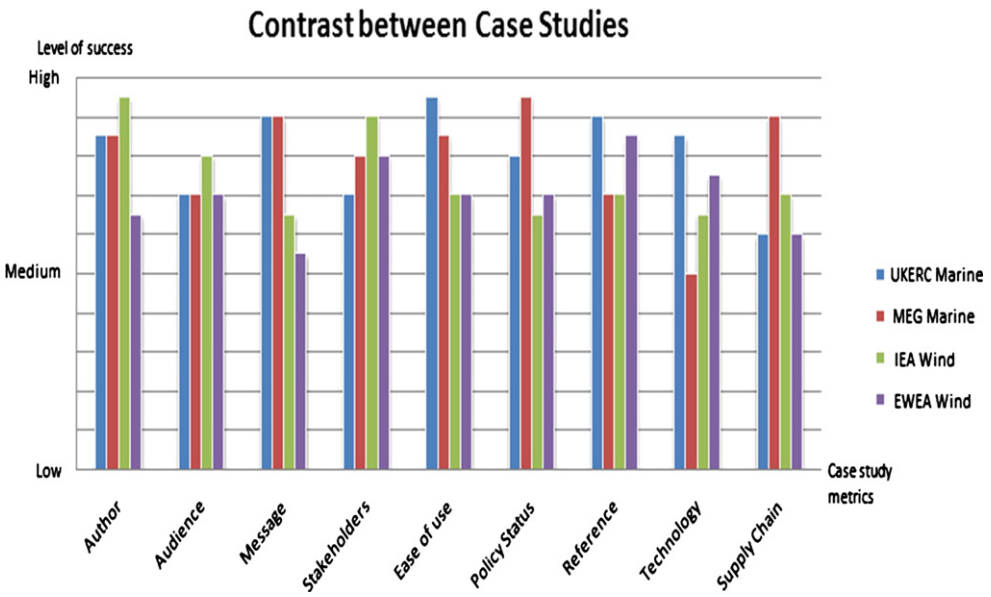

Fig. 3. Comparison of the four roadmaps across the nine metrics.

5.2. Target audience

It was judged that all four roadmaps effectively address their full target audiences.

The UKERC and MEG roadmaps focus heavily on technology and policy, and supply chain aspects respectively, utilising their key stakeholder strengths in these areas to prioritise issues that may present bottlenecks to industry development. It was judged that, despite incorporating other aspects to maintain a complete approach, both the UKERC and MEG roadmaps would better cater to their full target audience if a more balanced approach was taken.

Of the four roadmaps, the IEA roadmap, which successfully addresses the entire global wind energy sector, scores the highest against this metric. The roadmap effectively addresses emerging regions as well as regions of advanced wind energy development and condenses a large quantity of material, from a broad range of stakeholders, into a well balanced roadmap.

5.3. Roadmap message — effectiveness of delivery

The UKERC and MEG roadmaps score the highest against this metric. It was judged that both roadmaps (despite a heavy technical focus in the UKERC roadmap) adopt a very effective, concise yet sufficiently technical approach, and can be read and understood by any stakeholder. The roadmaps are written in a concise and factual fashion, deliver their objectives and recommendations in an effective format, avoid sales or lobbying language, and utilise clear and focussed graphics to deliver the roadmaps' message effectively.

The EWEA roadmap scored the lowest on this metric. In contrast to the rest of the roadmap which is intensely technically detailed, the first section uses a lobbying type style which could be patronising to their target audience. It was judged that trying to incorporate too much and utilising inconsistent language in different sections ultimately detract from the roadmap's effectiveness.

5.4. Are the stakeholders adequately addressed?

All four roadmaps scored well against this metric, with the IEA roadmap receiving the highest score. How the stakeholders are addressed is closely linked to how stakeholders were involved in the development of the roadmaps. A robust roadmapping process which involves a diverse range of stakeholders is likely to address all stakeholders evenly and adequately.

Despite scoring well, it was judged that each of the UKERC, MEG and EWEA roadmaps were detracted from by being too focussed on specific aspects of the respective sectors (for example, the UKERC roadmap's heavy technology focus). However, it is important to note that focussing on specific aspects shows that the author has prioritised the roadmap's focus to achieve its main objectives. This approach achieves successful results in all three roadmaps, but results in lower scores against this metric.

The IEA roadmap achieves the highest score against this metric because it compiles input from a wide range of highly regarded stakeholders from around the world, and recommends specific actions for different stakeholder groups. This method, breaking

down the necessary actions for industry, government, and power system actors, with different underlying objectives for each group of stakeholders, was judged to be very effective.

5.5. Ease of use — method used

The UKERC roadmap scores the highest against this metric and was judged to deliver its message very effectively, be easy to read and follow and use concise and consistent language whilst still including sufficient detail. It was judged that the roadmap (using a combination of workshops and interviews) utilised a clear and effective implementation process, resulting in a simple, concise and user friendly roadmap for readers from all backgrounds. The roadmap also utilises a repetitive format and common graphs throughout, increasing reader familiarity with the overall objectives and how the recommendations and objectives are interlinked.

The IEA and EWEA roadmaps received the lowest scores against this metric. The EWEA roadmap has a robust structure: describing (in each of the four technical sections) the current status of the sector followed by details on how to achieve the roadmap's recommendations. However, despite effective use of graphs, it was judged that the EWEA roadmap contains too many distracting images, and that inconsistencies across the roadmap detract from its overall ease of use. The first section has a lobbying style which is ineffective for its target audience, while the remaining sections are too intensely detailed for some stakeholders to understand, resulting in an unbalanced and inaccessible document.

5.6. Status of suggested policies

The MEG roadmap achieves the highest score against this metric, because its main policy recommendations have been acted upon by the roadmap's principal target audience. This is largely attributable to the fact that the roadmap's principal target audience, the Scottish Government, was a key stakeholder providing input for the roadmap. The roadmap uses this input to strategically plan how the policy recommendations are going to be achieved. The roadmap's success also highlights the benefits which can be realised by using a roadmap to keep lines of communication open with the target audience.

The MEG roadmap has a number of key policy recommendations which have been realised in line with the roadmap's recommendations. These include, for example, the fact that – in line with the roadmap recommendations for updated planning policies – the UK Marine Policy Statement [28] and Scottish Marine Bill [29] both outline plans to streamline planning, licensing and environmental issues for marine projects.

The IEA roadmap received the lowest score against this metric due to the fact that the roadmap gives policy guidelines rather than specific targets and timescales. The roadmap scores poorly due to the general nature of its guidelines (necessary to address all stakeholders internationally) and because countries are at different stages of implementing these guidelines.

5.7. Citations and references

The UKERC roadmap scores the highest against this metric, due to the high number of citations it has received from international governments, academic papers, and more recent roadmaps in the sector. The US Department of Energy (DoE) draft Marine Roadmap [30] and the EU-OEA's European Roadmap [31] are both built on UKERC work [32]. In addition, since publishing the roadmap, the UKERC roadmap authors have been involved in activities including working with the Energy Technology Institute (ETI) on a joint technology roadmap [32], contributing to the Scottish Government Marine Energy roadmap [26], and assisting in preparing the Department of Energy and Climate Change (DECC) Marine Energy Action Plan 2010 [32].

The EWEA roadmap has received a significant number of citations but, in comparison to the UKERC roadmap, they are limited to primarily industry. The roadmap is not cited in a number of academic articles published in 2010 on developing the European offshore grid system which is a key focus of the roadmap, suggesting that not all stakeholders agree with the roadmap's recommendations.

The IEA and MEG roadmaps are not cited to the same extent as the other two roadmaps. The focus of the MEG roadmap on the UK and specifically Scotland also means that it is not as exposed to international stakeholders as a European or international roadmap, which may explain the fewer citations it has received. However, it is important to note that both roadmaps are relatively new, and (especially the IEA roadmap which has objectives out to 2050) it is expected that the roadmaps will be used more extensively in the future and increasingly cited if they are successful.

5.8. Technology

The UKERC roadmap scores the highest against this metric, with technology development as the roadmap's key focus and many recommendations already achieved. Important technology objectives which show signs of progress in line with the roadmap's recommendations include:

- The roadmap recommends full scale test sites available by 2010. In line with this, full scale testing facilities are now available at three UK sites.
- The roadmap recommends best practice and standards in place by 2015. EMEC are developing a full list of standards for the IEC [33].

- The National Grid Offshore Development Information Statement [34] is in line with the roadmap's recommendation that provisions for an offshore grid are in place by 2010.
- In line with the roadmap's recommendations, power take off and control, moorings, and modelling facilities are each being focussed on by various research institutions around the UK.

The EWEA roadmap also scores highly on this metric as its two main recommendations for the development of the pan-European offshore grid system (which is the main technology focus of the roadmap) have been acted on by the European Commission (EC) and the European Network of Transmission System Operators for Electricity (ENTSO-E).

The MEG roadmap scores the lowest as its technology recommendations have not yet been realised. However, this doesn't mean it is unsuccessful overall as policy and supply chain are its main focus.

5.9. Supply chain

The MEG roadmap scores the highest against this metric. Supply chain is a key focus of the roadmap, and this clearly shows that the roadmap successfully prioritised its focus on an area where it had particularly strong stakeholder input from government and industry. Many of the MEG roadmap's recommendations have been swiftly implemented and it was judged that the roadmap has had a significant influence on developments in the supply chain. Supply chain developments in line with roadmap recommendations include:

- The roadmap recommended that EMEC should develop a test site for scaled down devices. In line with this, EMEC have been awarded £8 m from DECC to develop testing facilities for $^{1}/_{4}$ and $^{1}/_{2}$ scale devices [35].
- Highlands and Islands Enterprise (HIE) and Scottish Enterprise have developed a National Renewables Infrastructure Plan to address offshore renewable supply chain requirements in Scotland [36].
- The first annual Energy Statement from the UK government promised increased support for the marine renewable supply chain [37].

The UKERC and EWEA roadmaps received the lowest score against this metric. Despite some good general points on the supply chain, which have subsequently been supported by NAMTEC [38] and built upon by SWDRA [39], it was judged that the supply chain doesn't receive enough priority in the UKERC roadmap and isn't as high quality as the rest of the roadmap. In the same vein, the EWEA roadmap's supply chain recommendations have so far had relatively limited success.

6. Recommended guidelines for implementing a successful roadmap

Following the case study results in the previous section it is clear that success factors and barriers to success for traditional roadmaps are still relevant. However, from the analysis conducted against the final four of the nine metrics developed, several important non-traditional success factors have also emerged. This supports the research hypothesis set out in the introduction that, as a result of the evolution discussed, the success factors for multi-organisation TRMs are different from those for traditional TRMs and new metrics for the evaluation of the level of success of TRMs are required.

Both the traditional and non-traditional success factors that emerged are developed in further detail in this section which develops a framework of eight success factors for contemporary multi-organisation TRMs, based on the insights which were revealed by the analysis in the previous section. Whilst the sample of the four roadmaps studied in detail is not representative, the

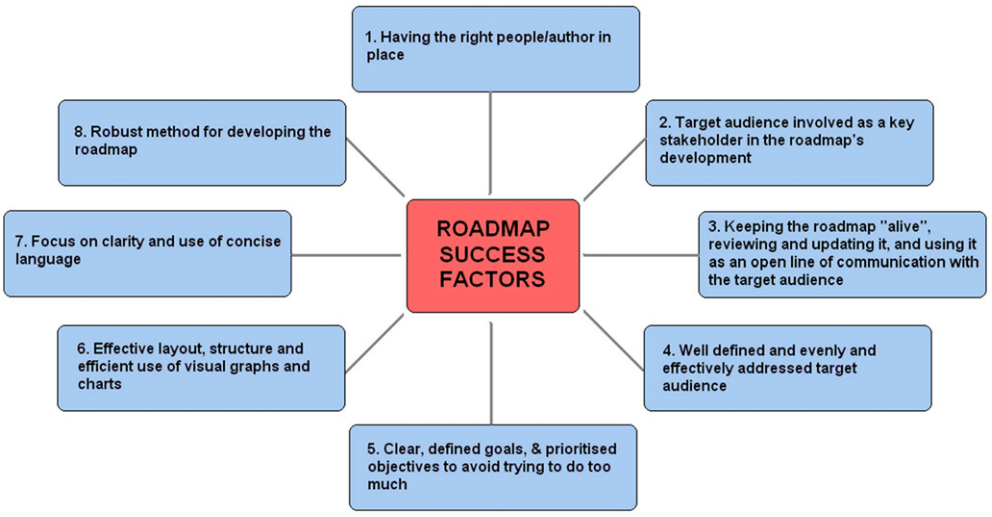

Fig. 4. Diagram illustrating the 8 success factors revealed by the analysis.

results indicate that the success factors revealed are applicable across energy sector TRMs and tentatively, across TRMs beyond the energy sector with similar authors and objectives. It is the recommendation of this paper that the success factors presented in Fig. 4 are crucial to ensuring that future roadmaps achieve success against the metrics developed and utilised in the previous sections.

The success factors presented in Fig. 4 are each elaborated on in the following subsections. It is important to highlight that the relationship between the eight success factors in Fig. 4 and the nine evaluation metrics in Table 1 above is not a simple linear relationship where there is one success factor derived from the analysis of each of the nine metrics.

6.1. Having the right people/author in place

Selecting the right people throughout the process is a traditional success factor. Appointing authors with strong reputations and including input from a wide range of stakeholders (spread across industry, academia, and government) is important to ensure a well balanced approach. As roadmap authors have evolved from individual companies to consortia of companies and even entire industry sectors, combined with the need for multi-organisation roadmaps to address a much larger and more diverse target audience than a traditional TRM, this success factor has become increasingly important.

6.2. Target audience involved as a key stakeholder

Having the roadmap's intended target audience involved as a key stakeholder, providing input for the roadmapping process will increase the likelihood that the roadmap's suggested recommendations are acted upon. This is an emergent success factor which is closely linked to the fact that for many multi-organisation roadmaps, the intended target audience (and the decision makers responsible for committing to implementing the roadmap's recommendations) are a different organisation than the organisations which are coming together to produce the roadmap. This is the case for each of the four roadmaps analysed in this study, and is in direct comparison to traditional TRMs where the key decision maker is usually the company's senior management. This success factor is built upon a traditional success factor, acknowledged by Phaal et al. [23], that a roadmap must have commitment from senior management. It is important to note that, in the case of the four roadmaps analysed, the principal target audience for the majority of the recommendations are government actors.

6.3. Keeping the roadmap “alive”; reviewing and updating it, and using it as an open line of communication with the target audience

Reviewing and updating a roadmap is important to keep stakeholders in regular contact and is a traditional success factor. For many roadmaps, the most important channel of communication to keep open is that between the target audience and the stakeholders developing the roadmap and this could avoid delays caused by slow communication. Similar to above, this is a subtle evolution from a traditional success factor. Gerdsri et al. [24] and Phaal et al. [23] identified “continuation of the TRM implementation” and “keeping the roadmap process ‘alive’ on an ongoing basis” as important traditional success factors. It has been identified that the scope of this process of keeping the communication channels open between stakeholders can be usefully widened to include the target audience, which in the case of the four roadmaps analysed, were government actors.

6.4. Well defined and evenly and effectively addressed target audience

It is important to have a well defined target audience. Having input from a wide range of stakeholders across government, academia and industry, ensuring that the roadmap targets all classes of stakeholder and striking a careful balance between a broad approach and a prioritised approach are all critical to evenly and effectively addressing all relevant stakeholders. This is closely linked with having clear defined goals and prioritised objectives to avoid trying to do too much. For a traditional roadmap, the target audience is usually the same company which is responsible for developing the roadmap. This is not the case for many multi-organisation roadmaps, which have to effectively and evenly consider a wide and diverse array of target stakeholders. However, this success factor is really only a subtle evolution from the success factor identified by Gerdsri et al. [24]: ‘acceptance by key stakeholders’.

6.5. Clear goals and prioritised objectives to avoid trying to do too much

The roadmap must have clear and defined goals set out early in the process. It is also important for a roadmap to prioritise its objectives and not try and do too much. Roadmaps need to achieve a careful balance between maintaining a broad approach to evenly and effectively address their large stakeholder audience, and prioritising focus on important aspects of the industry that are identified as presenting potential barriers. Roadmaps which successfully prioritise their objectives have an increased likelihood of the roadmap's key recommendations being implemented. However, a careful balance is a critical success factor, as trying to do too much or too much focus on a particular aspect can detract from the roadmap's overall effectiveness.

6.6. Effective layout, structure and efficient use of visual graphs

It is necessary to deliver a high volume of information. Therefore it is important to have a clear, easy to follow format and approach which is consistent throughout. Effective layout, structure and visuals are principal to making the roadmap easy to use and delivering the roadmap message effectively. Using the same graph formats throughout can be a useful way of giving the reader a clear view of how all of the roadmap objectives will mesh together.

6.7. Focus on clarity and use of concise language

It is important for a roadmap to use clear and concise language that is sufficiently technical to address all technical recommendations without being overly technical and excluding non-technical stakeholders. This will allow the roadmap to be easy to follow and the roadmap message to be delivered effectively. Overly lobbying or technical language may exclude stakeholders and detract from the effectiveness of delivery of the roadmap's message.

6.8. Robust method for developing the roadmap

The process of technology roadmapping is often viewed as equally important as the document itself, and forms new working relationships among stakeholders. Selecting a roadmapping methodology that addresses all aspects of the sector in question, as well as integrating input from a wide range of stakeholders from across academia, industry and government, is critical to ensuring the roadmap has a well structured approach and addresses a full range of stakeholders.

The eight roadmap success factors revealed by the analysis are largely built upon traditional success factors, (outlined by Phaal et al. [23] and Gerdsri et al. [24] in Figs. 1 and 2 respectively) with a number of exceptions. For success factors one to four above, important points are highlighted where the success factors are distinct from or go further than the traditional success factors described in the academic literature. Success factors five to eight however, are generic success factors that apply equally to traditional roadmaps. These generic success factors are in close agreement with the work of Da Costa et al. [7], which states that "the main characteristics of successful roadmaps are their clarity with the focus put on the information displayed in the graphics, their synthetic view and their relevance to allow decision makers to concentrate on what is strategic for the decisions to be taken rather than being diverted by excessive detail".

7. Conclusion

This study corroborates and significantly adds to previous work which has identified the evolution of TRMs from traditional organisational TRMs (whilst acknowledging that traditional, single organisation TRMs are still a widely used and effective strategic planning tool).

The analysis revealed that, whilst traditional roadmapping processes and success factors are still relevant, roadmaps have evolved and a new type of multi-organisation roadmap has emerged which is much more dynamic with more information imbedded in it. The underlying reasons why the success factors are different from traditional success factors are based upon the difference in assumed level of commitment to implementing the roadmap. For a traditional, single organisation roadmap, if there is commitment to developing the roadmap from all stakeholders, including the main decision makers, it is reasonable to assume that there is a high level of commitment to implementing the roadmap's actions and recommendations. However, this assumption does not hold for many contemporary multi-organisation roadmaps due to the fact that (as illustrated by the four roadmaps analysed) the intended target audience of the roadmap and its recommendations are a separate entity than the collective authorship.

This is reinforced by a recent IEA document containing guidance for developing and implementing energy technology roadmaps [40], which is largely in line with both the traditional success criteria described in the academic literature, and with the success factors developed here. The report states that "even if a roadmap is well designed and has clear goals and committed participants, it still needs an audience committed to implementing it. Senior industry executives and/or policy officials must be engaged in the process, as they can authorise resources for the roadmap's completion and commit to implementing its findings."

This fact, that the intended target audience of the roadmap and its recommendations are a separate entity than the collective authorship, requires roadmaps to take on a more persuasive nature, based on the fact that they have to convince the intended target audience that the roadmap presents the best way forward for the sector in question and that they – as the responsible decision makers – should implement the actions and recommendations set out.

In general, for traditional TRMs, it is possible to ensure a high level of commitment to implementing the roadmap's actions and recommendations by taking care that the method utilised to develop the roadmap is robust and inclusive, ensuring the buy-in of all the necessary stakeholders — including the main decision makers. Acknowledging that, in some cases, aspects of in-company politics may exist which make a persuasive element to a traditional TRM necessary and mean that it is not possible to assume a high level of commitment to the roadmap, this is in clear contrast to multi-organisation TRMs where a defining feature, as revealed in the analysis, of many roadmaps is the fact that the intended target audience of the roadmap and its recommendations are a distinctly separate entity than the collective authorship. This is a key area of differentiation between traditional TRMs and multi-organisation TRMs.

It is clear that there is a recurring theme in the four roadmaps analysed in this study (and in a large number of contemporary multi-organisation roadmaps): the intended target audience for the roadmaps and their recommendations are government and political actors. Whether aimed at the UK or Scottish governments specifically, or more widely at European and international governments, this is the case for all four of the roadmaps analysed.

This is in alignment with the work conducted by Cahill and Scapolo [41] and Da Costa et al. [8], which has identified that since the mid-1990s, various actors have adapted the TRM methodology to provide the strategic intelligence needed by policy makers to optimise their decisions and investments in areas where science and technology play a prominent role.

Building on this work, this study has found that the evolution of the TRM process has led to the development of a new type of TRM: roadmaps whose principal purpose is political persuasion. This is a significant finding which builds upon the work identified above and which highlights the use of TRMs to provide intelligence for policy makers in areas where science and technology play a prominent role. Over and above providing the information to policy makers, necessary to optimise their decisions, roadmaps for political persuasion are focussed on influencing and persuading the policy maker to implement the recommendations set out.

TRMs have evolved from a purely strategic role (used by individual companies to guide their decisions and investments), to a persuasive and influencing role (roadmaps written primarily to persuade political actors that they present the best way forward). TRMs for political persuasion are commonly written by a collaboration of multiple organisations, often at a sectoral level, and aim to persuade and influence governments to implement the actions and recommendations set out.

The concept of TRMs for political persuasion adds to the work of Da Costa et al. [7] who developed the idea that TRMs for policy intelligence could assist policy makers under information overload and time pressure to grasp effectively the most important elements and relations within complex systems.

There are 3 important characteristics of TRMs for political persuasion, each of which is clearly different to those for traditional TRMs:

1. The author of the TRM is usually multiple organisations who have come together to develop the roadmap with a common objective.
2. The intended audience of the TRM is a separate entity than the collective author. The intended audience is often government, and is also often composed of multiple organisations/departments.
3. The purpose of the TRM is to persuade the target audience that the roadmap presents the best way forward and they should implement the actions and recommendations set out.

Traditional success factors for the author of a roadmap, the target audience, and the ongoing review/update of the roadmap have to be refined to suit this new, evolved type of roadmap for political persuasion. The role of government in TRMs is also very different for TRMs for political persuasion than it is for traditional TRMs, and this is clear from the analysis in this study. However, it is important to highlight that the important role of governments as the target audience of many modern day roadmaps, and the finding that – as the key target audience – governments should be directly involved in a roadmap's production, is in direct conflict with De Laat and McKibbin [10]. De Laat and McKibbin [10] stated that "…government has no major role in these [TRM] exercises, ultimately borne by the industry. It is the willingness of firms to cooperate, and even to initiate TRM, that is a major success criterion for TRM." This statement is refuted by the undertaking of a TRM for Canada's civil infrastructure systems in 2002 [42], and by the MEG marine energy roadmap [26] which both saw governments play an active role in the development of the roadmap and an active role in implementing the recommendations. Overall the paper by De Laat and McKibbin [10] is limited in its view of the role that government has to play in developing a TRM.

Every industry has its own unique barriers to be overcome, and as a result, roadmap authors need to tailor the roadmapping process to address issues specific to their industry. If this advice is heeded, the analysis conducted has yielded some important results that can be used by new authors looking to develop roadmaps for political persuasion in any sector.

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