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Four dimensional Science and Technology planning: A new approach based on bibliometrics and technology roadmapping

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ABSTRACT

Seemingly endless new technologies are emerging. Mapping out Science and Technology (S&T) planning correctly on the national level would help innovation shareholders remain current on technological development trends and gain an advantageous position among the fierce future competition of the global market. Thus, formulating effective S&T planning is significant for a nation, especially for new and emerging technologies. This paper proposes an industry S&T planning framework. Different from previous frameworks, this methodology's dynamic is directed in four dimensions (nation, technology, industry, risks and impacts), tries to find the key elements in a specific technology area, and aims to aid in national S&T planning. China's solar cell industry is employed as the case study.

1. Introduction

As globalization continuously advances, so does technology. This leads to the frequent appearance of candidate new technologies and the blossoming of some of those as Newly Emerging Science and Technologies [NESTs]. Compared to traditional technologies, emerging technologies are fast developing and have uneven and limited applications in the marketplace. Yet, one NEST may profoundly impact the global industrial and economic structures. The strategic importance of technology in delivering value and competitive advantage becomes more critical as the cost, complexity, and rate of technology change increase, even as competition grows and sources of technology globalization multiply [1]. These circumstances drive the need for nations to identify and grasp potential technology opportunities [2]. This paper presents an approach to set up planning for NESTs based on understanding national priorities in order to enhance technological innovation and international competitiveness.

Our four dimensional (nation, technology, industry, risks and impacts) approach seeks to integrate future-oriented technology analyses [FTA] into a national Science, Technology and Innovation [ST&I] policy framework. Regulation and policy instruments need support systems to augment their targets—a variety of (and often shifting) industrial contexts. This emphasizes the requirement for relevant and timely strategic intelligence to enable effective decision-making and strategy development for national S&T planning. Considering this, governments ought to seriously consider the following questions:

(1) How best to capture emerging technologies' development situation? Many existing approaches focus on exploring future possibilities, neglecting to make sure that we understand key "forces and factors" of the current situation [1,3–5].

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(2) How to build upon the current analyses to address the emergence and evolution of technology for the nation? Which dynamics are important? (This has implications for point 1.) What sorts of data and analyses are needed [5] to evaluate and prioritize NESTs?
(3) How best to evaluate not only the technology per se but also the industry to deliver that technology in the form of innovative products or processes?
(4) Considering social and environmental consequences that have indirect, externality, or unintended impacts, for good or bad, how does the NEST fit within the risk and regulation landscape?

These four points summarize many complex practical issues. We explore these four requirements, in different contexts and in projects that variously lean more on some elements rather than others. Our intent is to construct a hybrid innovation management model aiming to help a nation implement Science and Technology planning of an emerging technology with both qualitative and quantitative methodologies.

A number of additional questions are critical in analyses of target technologies. What is the current situation with respect to a given NEST for the nation? Most FTA approaches favor expert engagement, but identifying experts is a non-trivial task. In many cases, the types of actors to be engaged vary. Qualitative and quantitative methodologies must be combined into useful intelligence to feed into multi-actor engagement approaches.

This paper is organized as follows: Section 2 describes a four dimensional Science and Technology planning framework for emerging technologies. An empirical study of China's solar cell industry is used to verify the scientific and practical value of the model in Section 3. Finally, Section 4 presents conclusions.

2. Four dimensional Science and Technology planning approach framework

2.1. A tailored approach

Analysis of an emerging technology should elucidate technology policy and management issues and questions. Porter and Cunningham listed 39 tech mining questions and more than 200 indicators based on 13 Management of Technology ("MOT") issues [7]. These are just suggestions; the technology analysts need to work with the intended study users to determine what information would be most valuable in managing the technology in question and in what form. For emerging technologies, aiming for different targets, the questions could vary. Does this technology offer realistic innovation potential? What is driving such innovation? Are there potentially unintended consequences of manufacturing and introducing the resulting products (or processes)? The first two questions lay more emphasis on the technology while the latter question emphasizes industrial and societal factors.

To answer the spectrum of questions, we construct the framework in four levels for Science and Technology planning following the four dimensional idea. These four levels are 1) the national context for the target technology, 2) the target technology, 3) that technology's industry, and 4) potential impacts of target innovations. In this framework, each level provides the background and analysis base for the following one. We try to find the key elements in each level by answering the MOT questions to help set up the Science and Technology planning for an emerging technology.

Nations operating in competitive environments demanding process improvements, new product introductions, or technology-enhanced services must obtain and use information on emerging technologies [1]. Bibliometrics – counting activity levels and identifying patterns in R&D bibliographic records, plus patent analyses – has contributed to Science and Technology studies for decades [6]. With the expansion of databases that compile abstract records and of desktop computing power, text mining of those records further enriches the empirical base. "Tech Mining" [2] is our shorthand for such activities. It can help researchers and research managers understand the "research landscape" to identify what is already heavily studied and to help ascertain the best opportunities for further research.

However, limitations of bibliometrics also should be listed: (1) not all R&D is published or patented, and counts do not distinguish quality [2]; (2) not all publications or patents are similarly valuable; for example, patent barriers could have more business value than the technology itself; (3) timely and important information may be missing due to publishing lag times. At the same time, qualitative methodologies (e.g., Delphi) provide chances to compile diverse experts' opinions. They depend on experts' intuitive knowledge, but they may be biased since the opinion of experts may be influenced by subjective elements and limited cognitive horizons [8–10]. Accordingly, various researchers are working to combine qualitative and quantitative methodologies. Based on a national R&D program in Korea, Lee and Song selected the key research area in nanotechnology by fuzzy clustering methods with a questionnaire of 600 experts from government, enterprises, and institutions [11]. In our framework, we will employ qualitative analyses or quantitative analyses, or the combination of the two, for different levels based on their respective characteristics.

2.2. A Science, Technology and Innovation (ST&I) planning framework

The research framework is constructed as per Fig. 1.

Level 1—National Context for the Target Technology: In order to conduct strategic S&T planning, understanding the country's technological innovation environment is the first important step. The environment may include the current competitive situation, global and national technology policies, and market development. All of this information is required to determine whether the