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An Analytical Framework for a Technological Innovation System: the Case of a Nuclear Power System

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Abstract The aim of paper is to develop an alternative framework for the study of technological innovation systems. In contrast with conventional literature, this analytical framework is designed for entrepreneurs, i.e. actors, at the micro level rather than policy-makers at the meso or macro level. Herein, the entrepreneurial innovation system is conceptually refined by synthesizing knowledge regarding technological innovation and innovation systems. Drawing upon the intrinsic technological identity essential for innovation, the entrepreneurial innovation system is shown to involve three core changes in terms of technology, organization and market, and their couplings within its internal boundary over time. This analytical framework also takes into account the fact that the innovation system is influenced by and copes with the external environment during its evolution. Moreover, the framework of the entrepreneurial innovation system considers the recent trend of sustainable development. The technical and socio-economic characteristics of a nuclear power system are studied empirically to articulate an analytical framework that should be very useful for technological innovation in other energy systems by reflecting their unique features.

Keywords Analytical framework, technological innovation, innovation systems, entrepreneurial innovation system, nuclear power generation

I. Introduction

From the perspective of a technological innovation school, the aim of this research was to find an alternative approach to show how to design ex-ante and analyze ex-post a technological innovation system along with its dynamic process and performance. Because technological innovation has been widely recognized as one of the primary engines of economic growth, the so-called technological innovation system (TIS) approach has been developed to understand better technological innovations in a systematic way. More

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specifically, it was developed to analyze the coherent linkages between technological change and economic growth while focusing on a specific field of technology (Carlsson, 1994).

Despite the increasingly wide diffusion of the concept, the TIS approach has not reached common consensus yet in terms of structure and process. It has been applied to different levels of analysis and described in various ways. First, the definition of TIS considers broadly a specific area or field of technology as a level of analysis, which allows wide scope for describing various TISs involving different levels of analysis (Carlsson et al., 2002; Truffer et al., 2012). The TIS framework has been applied to at least five different units of analysis, including a specific field of knowledge (e.g. microwave engineering), a particular technology (e.g. biocompatible materials), a product or an artifact (e.g. CNC machine tools), a product group or set of related products (e.g. factory automation), and a sectoral focus (e.g. electronics industry or biomedical industry) (Carlsson et al., 2002; Truffer et al., 2012). Second, from its beginning the TIS has been used to support policy making (Carlsson et al., 2002; Bergek et al., 2015). As a branch of innovation systems, the policy-view TIS is also to analyze heuristically all societal subsystems, actors and institutions linked to technological innovation (Hekkert, et al., 2007). Its definition covers not only creating and diffusing, but also utilizing innovations while encompassing markets and users.

In this perspective of policy-making and analysis, most TIS studies have typically highlighted the strengths and weaknesses, the drivers and barriers, and the static structures and dynamic processes of TISs (Hekkert et al., 2011; Truffer et al., 2012). The traditional literature hardly develops the framework, focusing more on the actors than policy makers, although they stress very strongly that no innovation system exists without entrepreneurs. "In whatever country and in whatever institutions the original scientific and technical ideas, which underlie a new technological system, may have originated, the ability to innovate successfully and continuously depends upon the number and quality of the people who have assimilated these ideas and the depth of their understanding" (Freeman, 1982: 11). "In the presence of an entrepreneur […] such networks can be transformed into […] synergistic clusters of firms and technologies which give rise to new business opportunities" (Carlsson & Stankiewicz, 1991: 93). Third, the traditional use of TISs as a policy tool shows that the frameworks could be strengthened more coherently by making the interactions between the TIS and its contexts explicit in their concepts. Even though the internal systems, called the focal TISs, are distinguished, external contexts are also included in the technological innovation system (Bergek et al., 2015).

However, the entrepreneurial innovation system (EIS) proposed in this paper considers that the focal TISs do not interact reciprocally with the external environment. The entrepreneur-view TIS is not able to directly control and address issues in external contexts. Instead, the EIS opens up such possibilities that its process and performance might change the external environment. For example, the EIS could be used to try to gain government policy support and social legitimacy. The performance of the EIS may result in external contexts as it diffuses widely and deeply into the general socio-economic system. However both external changes are beyond the internal power of entrepreneur. Last, as long as the entrepreneurial activities are stressed in the system, the TIS focus should be narrowed to micro-level. Conventional TIS frameworks, largely due to their policy-making perspective, are usually limited to meso-level studies, which are difficult to be applied to micro-level systems (Markard et al., 2015). However micro-level studies should be incorporated into meso-level considerations to understand the TIS more comprehensively (Markard et al., 2015).

Bearing this in mind, the aim of this paper is to develop a method appropriate for understanding better technological innovation systems (TISs) from the position of entrepreneurs, i.e. from an angle different from that in conventional literature. This opens up two research questions: what differences in analysis of TISs are needed to provide the perspective of entrepreneurs rather than policy makers, and what changes from conventional TISs are needed to create the entrepreneur-view TIS. First, some relevant theories regarding technological innovation and innovation systems are assembled to define and conceptualize an entrepreneurial innovation system (EIS). Second, the conceptual framework is further elaborated to identify key elements and their interactions to develop its analytical version. Last, taking a nuclear power generation system as a case, the new analytical framework is tested for use in terms of its validity and reliability. Thus, this research was done to explore and develop an analytical approach for an entrepreneurial innovation system (EIS) with its underpinning concept and elements. Chapter 1 provides the background to the research and introduces its objectives and questions. It also outlines the research method including data collection and analysis. Chapter 2 reviews traditional frameworks linked to technological innovation and innovation systems to refine the concept of the EIS in Chapter 3. The new EIS is applied to nuclear power generation in Chapter 4 and 5. In Chapter 4, the internal elements of the EIS are examined including organizational, technical and market change based on technological identity.

The external environment is considered in chapter 5. The results of empirical investigation are embedded within the EIS in chapter 6, in which an analytical framework of EIS is developed for the technological innovation of a nuclear power system. Chapter 7 provides a summary and a proposal for further refinement of this framework.

II. Evolution of Innovation Systems

Thanks to Schumpeterian and Neo-Schumpeterian economics, it has been widely accepted that technological progress is one of the primary engines of industrial development (OECD, 1996; Kim, 1999), and national economic growth (Rosenberg, 1982; Nelson & Winter, 1982). While creating improvements in the productivity of capital and labor, and the creation of new goods and services, technological innovation contributes significantly to the growth of the specific industries concerned and to the overall economy in both developed and developing countries (Mitchell, 1999). Schumpeterians and neo-Schumpeterians view technological advancement as the central force in economic phenomena, i.e. one of the endogenous determinants of economic development. However, the two schools operate from different perspectives as to see what kinds of technological change are more significantly associated with economic growth. Schumpeterians focus on the radical change induced by discontinuities in technological innovation to expand the international technology frontier.

The neo-Schumpeterian view of technological change is not so much about one single major event, as it is about an evolutionary process in which the incompleteness of the radical breakthrough is successively improved by a series of complementary innovations (Kim, 1994). Thus, neo-Schumpeterians view technological innovation as an evolutionary process of technologically diverse solutions and selection mechanisms to substitute for less-desirable technologies. Their desirability focuses especially on cost advantages, technical superiority and evolutionary potential (Nelson and Winter, 1982; Arundel et al., 1998). Although Schumpeter looked at radical innovations, he conceptualized comprehensively technological innovation as 'the new combination of productive means, or materials and forces, which happen to be unused', enterprise as ''the carrying out new combinations of productive means'. (Schumpeter, 1934: 65-67). He considered entrepreneurs as people who carry out enterprise, or innovation. Following Schumpeter, Freeman (1982) defined innovation as 'the commercial realisation or introduction of a new product, process or system in the economy' (Freeman, 1982: 9). In this sense, technological innovation is comprehensively defined as the process for carrying out a new combination of productive means and or new products that are realized commercially in the markets so that can create new socio-economic value in the economy and in society.

Analytical frameworks of innovation systems were coined and conceptualized in the 1980s. The earliest versions of innovation systems were created at the national level as a combination of the perspectives of two pioneers, i.e. the SPRU (Science and Technology Policy Research Unit) at the University of Sussex in the United Kingdom and the IKE (Innovation, Knowledge and

Economic Dynamics) group at the Aalborg University in Denmark. The SPRU pioneered the analysis of the role of national science and technology systems on international trade performance and domestic economic growth. This perspective was reflected in the work of Freeman (1982) where the national innovation system was coined as a basic concept. The SPRU also explored the interaction between organizations participating in industrial enterprises through a series of empirical projects (Lundvall, 2016). The IKE research on innovation, knowledge and economic dynamics brought about an innovation system approach that was developed by integrating evolutionary economics with the concept of national production systems (NPS) used by the French Marxist structuralists. Moreover, the IKE scholars paid particular attention to learning as well as innovation. Taking these together, Lundvall (1985) presented an innovation system framework to provide better understanding of technological innovation and learning while focusing on the process of user-producer interactions (Lundvall, 2016).

As referred to in Lundvall (2003 & 2016), Freeman (1982) established the terminology of the national innovation system (NIS), which was prepared for the OECD (Organization for Economic Co-operation and Development) as an unpublished paper in 1982. Lundvall (1985) might be the first reference with ISBN number to the system of innovation, or innovation system (IS) as a booklet published by Aalborg University Press in 1985. Freeman (1982) coined the expression of national innovation system (NIS) in line with studies of the evolution of factors affecting international trade performance, which focused on 'ways in which competition is waged between firms and the measures taken by governments to help them' (Freeman 1982: 3). The Freeman (1982) approach began with accepting the idea that technology is an important element in the ever-changing market competition, which could be managed by appropriate policies at the level of both firm and nation-state. He attempted to explain why the NIS is so important for the international competitiveness of nations.

He analyzed the influence of science and technology systems on international competitiveness at the macro level while showing particular concern about the different ways of organizing an innovation system and its dynamic evolution over time at the micro level. Based on a historical review, he argued that the way innovation systems were organized was a dominant element in changing international technological leadership and in turn the international competitiveness of firms and nations. Freeman (1982) ended his discussion of the NIS concept by emphasizing the systematic combination, i.e. coupling mechanisms of policies for science and technology with policies for international competitiveness of domestic industries. "At the national level, […] long-term infra-structural investment in 'mental capital' and its improvement is crucial for successful economic development, and for competitive trade performance. Whilst this necessity may be mitigated to some extent by fortunate natural resource endowment […], it is an important issue for all. […] The 'coupling mechanisms' between the education system, scientific institutions, R&D facilities, production and markets have been an important aspect of the institutional changes introduced in the successful 'overtaking' countries. […] As at the enterprise level, the study of effective national competitive strategies must fully take into account those organisational and social factors, which make the difference between success and failure." (Freeman, 1982: 23).

Lundvall (1985) expressed a 'system of innovation' as a linkage between professional organizations that engage in different types of innovative activities and interact tightly with one another in learning about and producing innovation. The concept of an innovation system is rooted in specific patterns of professional user-producer (recipient-donor) relationships in the process of R&D and production for creating innovation. Lundvall (1985) linked the concept of an innovation system to university-industry partnerships and to user-producer interaction for product innovations at the micro level. In particular, Lundvall (1985) regarded innovation as an interactive process in which the role of users is very important for the development of new products and processes (Lundvall, 2016). Lundvall (1985) expanded the concept of innovation systems from micro to macro level because this brought vertical integration of user-producer interactions, crossing the traditional borders between sectors and industries. He also viewed the world economic system as a complex network of user-producer relationships connecting units dispersed in economic and geographical space, and argued that national policies should stimulate the reshaping of user-producer linkages to promote innovative activities and economic growth (Lundvall, 1985)

There are some differences between the two. Freeman (1982) placed more weight on the macro level between the national innovation system (NIS) and international trade performance while emphasizing that the NIS is based on systematic couplings between technologies, entrepreneurs and markets at the micro level. Lundvall (1985) viewed an innovation created and diffused by an interaction between user and producer at the micro level, which was expanded to the national level by introducing vertical integration. Nevertheless, it is worthwhile noting that the first two pioneers created the frameworks for national innovation systems, which contributed to understanding systematically the role of technological innovation in international trading performance and national economic growth (Lundvall, 2016). It is also recognized that the NIS frameworks are still valid even in the era of globalization, in particular when technical opportunities and user needs are complex, technical change occurs discontinuously and tacit knowledge is more dominant than codified one. Under these circumstances, geographical, linguistic and cultural distance beyond national borders will make the innovation operate much less effectively and efficiently (Lundvall, 1985). '[…] In the increasingly serious international conflicts, about which countries are paying for (the United States) and respectively appropriating benefits from (Japan) the investment in science and development of new technology, it is important to understand how different and very diverse national systems work.' (Lundvall, 1992: 89)[1]. 'It has become even more important to be explicit about the national dimension as ''globalization'' becomes a major theme in the societal discourse.' (Lundvall, 2007: 100).

However, the complexity of the NISs and the expansion of globalization gave rise to disputes over the generic nature of the NIS frameworks (Metcalfe, 1994; Hekkert, et al., 2007). It is reported that it is very difficult to understand the overall network of innovation systems at the national level due to the countless number of elements and their interactions, which involve actors, technologies, knowledge, institutions, markets, and so on. Moreover as learning about the knowledge and user-supplier links gets more international, international collaboration is increasing between actors in their innovation projects (Metcalfe, 1994; Hekkert, et al., 2007). According to Lundvall (2007), since the 1990s, several new concepts of innovation systems have been developed. Swedish scholars such as Bo Carlsson and his colleagues presented the concept of technological systems (Carlsson, 1994; Carlsson and Stankiewicz, 1991). Franco Malerba with colleagues conceptualized the sectorial innovation system (SIS) (Breschi and Malerba, 1997; Malerba, 2002). They found that the institutional framework for an innovation system varies significantly with the core technologies concerned in the system and paid more attention to the knowledge characteristics of the innovation system rather than national boundaries (Metcalfe, 1994). Although much room remains for improvement, concepts supporting specific technologies and sectors have been gaining ground.

Carlsson and Stankiewicz (1991) first expressed a technological system (TS) as a framework alternative to innovation systems (ISs) (Truffer et al., 2012). Carlsson and Stankiewicz (1991) highlighted that technological systems in a specific area of technology are the essential drivers of economic development. From this perspective, a technological system is defined as a dynamic interaction of agents to generate, diffuse and utilize technology in a specific area of technology under a particular institutional infrastructure (Carlsson and Stankiewicz, 1991; Carlson, 1994; Carlsson et al., 2002). Thanks to organizational efforts of entrepreneurs, such technological systems can be transformed into synergistic clusters of agents and technologies in a specific technology area which leads to new business opportunities and in turn to economic development (Carlsson & Stankiewicz, 1991). While focusing on a specific technology area rather than territorial boundaries and sectoral dimensions, the TS could be influenced, i.e. facilitated or impeded by national elements such as cultural, linguistic and other socio-political circumstances

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[1] This paper reviewed Lundvall (1992) in Lundvall (2016), therefore the page specified in this paper came from Lundvall (2016), not from Lundvall (1992).

(Carlson, 1994), and by some sectoral elements such as societal functions of sectors and competitions between technological fields within each sectors. This TIS approach, using a special framework of innovation systems, contributes to reducing the complexity of the NIS and SIS, and enables to better analyze the coherent linkage technical change to economic development in ways that are as comprehensive and systematic as reasonably possible (Carlsson & Stankiewicz, 1991; Hekkert, et al., 2007)

Since their inception, the TS frameworks have shown some refinements. One significant development is that more attention is being paid to emerging technologies as well as to incumbent ones (Hekkert & Negro, 2011; Markard et al., 2015). In the original version of TS, more emphasis was placed on the diffusion and utilization of existing technological fields while much less attention was paid to creating new ones (Carlson, 1994; Lundvall, 2007 cited by Hekkert et al., 2007). The framework has become used to deal with emerging technologies and compare them with the existing ones in terms of the structural network and dynamic process of innovation systems (Hekkert & Negro, 2011). In addition, it is widely recognized that not only building up the system, but also running it determines the success of the TS (Hekkert et al., 2007; Hekkert et al., 2011; Truffer et al., 2012). Because the framework stresses organizational activities called "functions", understanding what kind of functions support or hamper the smooth running of the system becomes essential for the success of innovation (Hekkert et al., 2007). Among organizational processes, some are particularly highlighted: knowledge creation and diffusion, influence on the direction of the search, entrepreneurial experimentation, market formation, creation of legitimacy, resource mobilization and development of positive externalities (Truffer et al., 2012).

Going through this elaboration, it seems that this framework shifted from being labeled technological system (TS) to technological innovation system (TIS). The TIS emphasized the importance of creating technological innovation and the organizational functions much more than the original TS version. According to Markard et al., (2015) the term 'technological innovation system (TIS)' was coined in 2008. Since then, the term TIS rather than TS has usually been used to analyze and design the innovation of a specific technological field in terms of its structure and dynamic process (Hekkert et al., 2011; Markard et al., 2015). "The technological innovation systems (TIS) approach has gained quite some attention in recent years for the study of emerging technologies in and beyond the context of sustainability transitions." "From 2008, when the term was coined, to 2014, […] more than 80 papers, which refer to "technological innovation systems" […] this number does not cover the many publications […] under the notion of 'technological systems' since 1991." (Markard et al., 2015: 76). Thus, the TIS framework has theoretical position within the context of the innovation systems in that it focuses on explaining the nature and path of the dynamic causality of technical change with economic growth in terms of knowledge and competence rather than of ordinary goods and services (Carlsson & Stankiewicz, 1991; Hekkert et al., 2011).

The sectoral innovation system (SIS) is defined as “a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products.” (Malerba, 2002: 248). The concept of SIS attempts to present the multidimensional, integrated and dynamic view of technological innovation at the sector level. Individuals, organizations and their combinations can be actors at various levels of aggregation. They interact through various channels of cooperation and coordination, which are manipulated by institutions (Malerba, 2002). The concept of SIS is rooted in different technological regimes under which different sectors and industries operate. The SIS framework regards the regime as particular combinations of knowledge characteristics, technological competence, business opportunity and relevant institutional guidance (Carlsson et al., 2002). The SIS evolves over time along with change of the technological regime, which reflects the change of internal competitive relationships among firms and industries within a sector and/or external socio-economic landscapes (Carlsson et al., 2002; Malerba, 2002). The SIS framework aims at understanding not only the innovation structure and boundary of a sector, but also the difference in performance of firms and countries in the target sector (Malerba, 2002).

III. Conceptual Framework for the Entrepreneurial Innovation System

Following both Schumpeterian and neo-Schumpeterian perspectives, the definition of technological innovation has some basic characteristics. First, technological innovation is the process of coupling technological opportunity and socio-economic needs (Freeman, 1982; Lundvall, 1985). Successful technological innovations require “to match new technical and scientific possibilities with the needs of potential users of the innovation” (Freeman, 1982: 10). Whether it is based on scientific discovery or not, invention is defined as a process of finding new technical possibilities, i.e. new ways of doing things in practice without economic consideration. Technological innovation needs coupling of inventions with users or customers through markets to add socio-economic value. ‘Most inventions never become innovations since there is many a slip between cup and lip, and the process of developing an invention to the point of commercial introduction is often long and sometimes expensive and risky too. […] the ‘coupling’ process between technology and the market (or simply users where markets are not involved) has tended to become increasingly difficult, because of the growing complexity of both.' (Freeman, 1982: 10). Second, by definition, technological innovation inevitably addresses uncertainty that is embedded in science, technology, market and a wider set of socio-economic environments (Freeman, 1982; Dosi, 1988).

This uncertainty is ascribed not only to lack of all the knowledge and information regarding techno-economic problems and their solutions, but also to the impossibility of accurate predictions of the organizational terms of technological innovation such as cost, time and performance (Freeman, 1982; Dosi, 1988). What will be done and in turn achieved in the future can hardly be known ex-ante with any precision before the activities are carried out and the outcomes occur (Dosi, 1988). "If it is possible, then what is being done is not innovation." (Freeman, 1982: 12). In the case of innovations that are simply copied or incrementally improved, this uncertainty can be substantially reduced in speculation on some of the problems or the solutions (Freeman, 1982). Third, technological innovations are cumulative in the diffusion process (Freeman, 1982; Lundvall, 1985; Dosi, 1988).

It seems that technological innovation hardly ends up as a single event, but rather as a series of further innovations through incessant transformation as the bandwagon gets rolling (Freeman, 1982; Lundvall, 1985; Dosi, 1988). In particular cases of incremental changes, the state-of-the-art technologies already developed and used elsewhere tend to lead trajectories of further innovations (Dosi, 1988). Last, it is true that any process of technological innovation is never performed without entrepreneurs. Furthermore, organizational efforts determine the success of technological enterprises to address the complexity and the uncertainty mentioned above. In following the original definition, the ability to manage business opportunities, technical change and market change is the central feature of any kind of innovation system and this ability is the one best exemplified by entrepreneurs. Put another way, entrepreneurs explore business opportunities and create technical change, which expands market varieties and in turn these are converted into socio-economic elements through selection in the process of diffusion (Carlsson & Stankiewicz, 1991; Carlson, 1994). Thus, organizational efforts led by entrepreneurs are the engine of technological innovation. Taking all the aforementioned features together, technological innovation refers to the process of coupling technology with market by entrepreneur within an uncertain context over time.

Taking notice of the fact that it is not policy makers, but entrepreneurs who take the lead in the entire process of technological innovation, in this paper we have attempted to develop an alternative TIS framework focused on the role of entrepreneurs in the system. This framework is labeled as an entrepreneurial innovation system (EIS) which is defined as the set of actors, technologies and markets of which dynamic interactions generate and diffuse technological innovations in a specific technology area within a particular external environment. This EIS approach takes root in the ground of traditional TISs. Figure 1 illustrates the position of the EIS under the TIS, which is related to the sectoral and national approaches. First, EISs are seeds taking root in a larger set of innovation systems (ISs). This is how the EIS can involve only the bare essentials of TISs and furthermore, any other conventional IS including SISs and NISs. Second, as long as the entrepreneurial activities of actors are much emphasized in the system, the TIS should be narrowed to the micro level from the meso level. Traditional TIS studies have contributed to better understanding of the complex and dynamic mechanisms of the emergence and growth of new industries in particular, and have hardly been applied to the micro-level systems (Bergek et al., 2015; Markard et al., 2015).

However the micro-level studies should be incorporated into meso-level considerations to understand the TIS more comprehensively (Markard et al., 2015). Third, at the micro level for entrepreneurs, rather than at the meso and macro level for policy makers, this EIS is not able to directly control and address issues in external contexts. The focal EIS does not reciprocally interact with external environments. Instead, the EIS admits the possibility that the process and performance might change external environments. For example, the EIS could be used to try and expect to gain government policy support and social legitimacy. In addition, an EIS may grow up so as to change external socio-economic systems significantly or radically. Nevertheless, external environments should still be outside the EIS because the system could not govern the changing process, nor plan a priori to change results as targets of the system.

In reflecting the definition and the immanent characteristics of technological innovation, an entrepreneurial innovation system (EIS) involves five basic dimensions: technological identity of a specific technical system, the changes of technology, organization, markets and a wider set of external environments.

Stressing the importance of the sharing goal over Fleck's concept of a system (1992:5)2, the term ‘system’ is defined as a set of things connected interdependently and in orderly arrangement, so as to form a whole complex that works together with some reasonably and clearly defined overall function and goal. Drawing upon intrinsic technological identity and initial market position,

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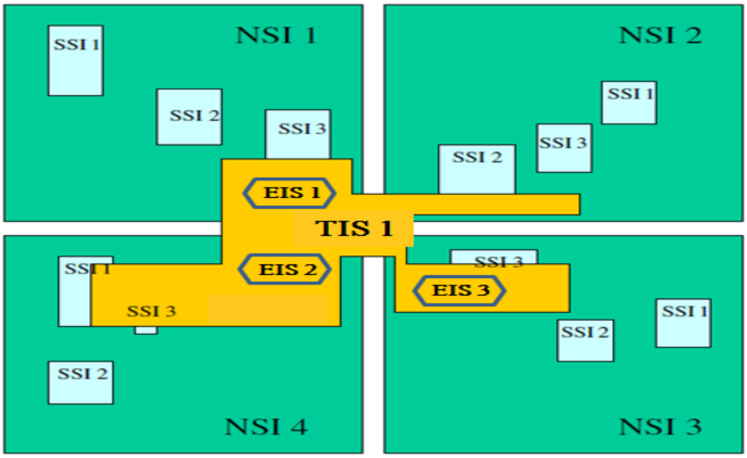
[2] The term 'system' refers to 'complexes of element or components which mutually condition and constrain one another, so that the whole complex works together, with some reasonably clearly defined overall function' (Fleck, 1992:5); According to Fleck's quotation from the Shorter Oxford English Dictionary , "System is a set or assemblage of things connected, associated or interdependent, so as to form a complex units: a whole composed of parts in orderly arrangement according to some scheme or plan, rarely applied to a simple or small assemblage of things."(Fleck, 1992: 5; quoted by Edquist, 1997: 13)

i.e. absorptive asset, at a given time, an EIS operates technological innovation as a continuous interactive course between organizational change, technical change and resultant market change while responding to changes in the external environment. Strictly speaking, technical change, organizational change, market change and technological identity are interconnected to constitute an EIS. This is because this paper assumes that the EIS does not control the external environment. Figure 2 illustrates the concept of an EIS.



*Note. This figure is borrowed from Hekkert et al. (2007) except that EISs is added by the author of this paper. In Hekkert et al. (2007), moreover the TISs are labeled as technology specific innovation systems (TSIS), which is differentiated from the TS in view of the so-called large technical system (LTS). This paper regards the TSIS to be included in the TIS.

Figure 1 Relations between EIS, TIS, SIS and NIS (Hekkert et al., 2007: 417)

To be more specific, technological identity are concerned with intrinsic scientific and technical natures of a technological system which are significantly different for a technology field and an industrial sector. Technological identity is likely to influence the ease or difficulty and the range of technological innovation (Pavitt, 1984; Dosi, 1988; Cohen and Levinthal, 1989; Carlsson, 1994). Moreover, technological identity influences technical paths while demanding distinctive utilization and modification of the technical system (Dahlman and Fonseca, 1987; Bell and Pavitt, 1993 & 1995). Technological identity also determines the organizational process in terms of the strategic position of the EIS, the degree of linkages between organizations, and the way and period of learning and investment (Bell and Pavitt, 1995; Najmabadi and Lall, 1995; Gonsen, 1998). Thus, it is necessary to identify the underlying technological identity of a specific technical system on which technological change is very likely to depend (Cohen and Levinthal, 1989).

Organizational change refers to change in the managerial efforts of entrepreneurs. Such organizational activities are required to explore business opportunity, mobilize assets and solve problems in planning, doing and seeing technological learning and innovation (Teece, 2007; Teece and Pisano, 1994; Kim, 1999). Appreciating the distinction between organizational change and technical change may be useful and important to understand the systematic causality of innovation systems. How entrepreneurial organizations are formed and run may have a great deal of impact on the ways that technological innovations are created and diffused. Furthermore, it has been demonstrated in a series of empirical studies that organizational change may play a key role in the shift from technical change to economic performance (Lundvall, 2007).

Technical change refers to the change of technical paths in the course of technological innovation. Through change in the contents of the technical system and the degree of the change, technical paths are addressed to pursue the optimization between the business opportunity and technical possibility of technological innovation. This is how technical path leads technological innovation toward new market positions (Dosi, 1982; Utterback and Suarez, 1993). Market change represents the change of market positions resulting from entrepreneurial innovations. From its definition, technological innovation is completed in markets.

It is not too much to say that all technical and organizational change exists only to add socio-economic value in the markets of private and/or public sectors. As the ultimate performance measure of the entrepreneurial innovation system (EIS), gaining competitive advantages in the market offers entrepreneurs socio-economic value-added. In addition, market change shows how much technological innovation works as the major determinant of industrial development and competitiveness (OECD, 1996; Kim, 1999), and national economic growth (Nelson and Winter, 1982; Mitchell, 1999).

Through market change, technological innovation is extended to the intimate relationship between human civilization and technological progress by the increase of economic variety and production productivity. The change of market structure by technological innovation reflects that markets are the link where micro-level innovation systems are tied to meso-level and macro-level ones.

Strictly speaking, external environments are not within the EIS. However, the EIS is linked to the environments to the extent that they have significant effect on the EIS. The predominant aspects of macro economy and general society require that technological innovation and learning should consider a wider set of institutional and cultural contexts. The term 'environment' is defined as all external forces beyond the control of the organization, which directly and indirectly influence the decisions and actions of an organization. There are generally two types of environments. One is the general environment (macro-environment), which usually impact indirectly on all or most organizations in the economy. They include the type of economic system (for example, free enterprise, socialist, communist), economic conditions (general prosperity, recession, depression), the type of political system (democracy, dictatorship, monarchy), natural resources (water, forests, oil, coal, soil), demographics (ages, genders, races, education levels represented in the work force) and cultural forces (values, language, religious influences). The task environment (micro-environment) includes the external forces that usually have direct effects on an organization's growth, success and survival. These effects concern stakeholders (customers to clients, stockholders and labor unions), market competition of inputs and outputs, government policies, global and domestic technical change, etc.

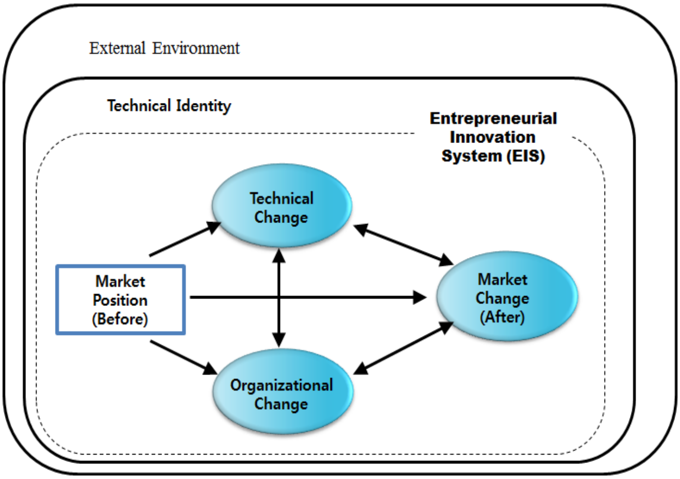


Figure 2 Conceptual framework of an entrepreneurial innovation system

IV. Entrepreneurial Innovation System of Nuclear Power Generation

1. Technological Identity

Technological identity represents intrinsic and generic characteristics of a technological innovation system that make it different from others. Technological identity consists of technical and socio-economic characteristics. Technical characteristics are identified in terms of technical structure and function of the relevant technology (technical system).

Technical structure represents what components constitute a technical system and how they are connected to each other (Chittaro and Kumar, 1998). The characteristics of technical structure should be evaluated on three aspects. First, technical complexity is evaluated by the number of disparate elements such as knowledge, material, components, parts, equipment and subsystems, which all together make up one technical system. Borrowing Utterback (1994)'s approach, this complexity may be seen by two extremes from homogeneous non-assembled to heterogeneous assembled ones (Utterback, 1994). The more the complexity is, the more difficult organizational effort is involved in its technical change (Walker et al., 1988). Second, knowledge intensity may explain how much knowledge strongly influences technological innovation. Knowledge intensity means the dependency of an entrepreneurial innovation system on obtaining, creating and using knowledge in the process of organizational change especially in learning, producing and marketing. The higher the knowledge intensity, the more organizational investment and effort may be required for the same amount of organizational activity. Last, technical novelty should be also counted to appropriately understand technological identity. Technical novelty refers to the progress of technological change in the global sense and can be explained by the life cycle of a technological innovation from its creation to its diffusion. Technological innovation is largely created by research and development (R&D) and diffused throughout the life cycle of the product group including relevant new and incumbent products. Therefore, technical novelty can be judged by the life cycle of deliverables of R&Ds and products of commercial production concerned with an entrepreneurial innovation system. While the technical complexity and the knowledge intensity explain the static configuration of a technical system, this technical novelty may change dynamically over its life cycle. In the case of technological catching-up in developing countries, it is particularly important to determine the level of technical novelty in the global sense. The progress of global technical change is very likely to determine the choices of technologies to be imported and the organizational ways to be mobilized for the catching-up (Fransman, 1984; Najmabadi and Lall, 1995; Kim, 1999).

Technical function is defined 'an effect the behaviour of the device has to have for letting the device's actions be successful' and describes what it does (Vermaas, 2010: 186). Technical behavior is defined as the change of physical state of a technical system and represents how structure of a technical system work in terms of variables and parameters that characterize its physical state and the scientific principles and laws that govern its operation. Two types of function can be generally defined. Operational function concerns whether the technical behavior of a technical system performs as intended in its design or not. It means a relation between the behavior of the structure of a technical system and its effect. Purposive function means a relation between the effect of technical behavior and the designed goal of the technical system for users. It concerns a state of real affairs in the society that is realized by using of the technical devices. For example, operational function of electric lamp is converting electricity into light and its purposive function is illuminating the room (Vermaas, 2010; Chittaro and Kumar, 1998). Purposive function is also linked to whether the relevant technology (technical system) is a product or a production process. Products are the final outputs of technological innovation (goods and services) to be traded in the markets. Products are carries technical functions to fulfill the needs of external users. Processes are the means of producing products usually to address the internal needs of the entrepreneurs. Process includes production equipment, facilities, task specifications, and work procedures (Lundvall, 1985; Afuah, 2003). It should be underlined that a process innovation on one side can be a product innovation on another. For example, if a company that achieves a successful process innovation and operates it for its own production lines ends up selling this process technology to others, the process technology for the seller's production line becomes a product for the new buyer (Lundvall, 1985). "If the process innovations are successful, the producer might appropriate them and present them to other users as a product innovation." (Lundvall, 1985: 9).

Associated with purposive function of a technical system, socio-economic characteristics describes why the technical system in the society and economy (Chittaro and Kumar, 1998) Socio-economic characteristics are evaluated in relation to three aspects: engineering economics, environmental and social compatibility. Engineering economics of a technical system refers to the cost of entrepreneurial efforts to perform an EIS over its lifetime. The total cost spent on providing a power plant for customers does not contain related subsidies and taxes that are included in price which can generate inefficiencies in the supply, distribution and use of the product. (IAEA et al., 2005: 18). Environmental and social compatibility may explain how much the technical system is associated with environmental protection and social stability. Environmental compatibility can be evaluated by analyzing what kinds of environmental risk might occur and how much they cause benefit or harm to natural ecological systems in the entire course of an EIS, in particular living things including human beings. Under the paradigm of sustainable development, social stability is evaluated by the size and degree of effect made by an EIS on social stability. In the case of energy service, electricity can be an invaluable means of improving social stability if it is accessible to all income groups (Modi et al., 2005). These environmental and social stresses caused by an EIS are likely to threaten back its economics while imposing increasing economic uncertainty and demanding technical change of an EIS.

A nuclear power system converts nuclear energy to electric energy as seen in Figure 3 (Kim, 2011b). Some of the primary energy in uranium-235 (U-235), or nuclei of U-235, is released by fission of atoms to produce heat, which is used to create steam under high pressure in 'nuclear steam supply system (NSSS)' to drive turbine-generators that transform mechanical to electrical energy (electricity). The electricity produced by nuclear power plants (NPPs) is transmitted to distribution grid systems (KAERI, 2007). A nuclear power system is composed of a required set of chemical and physical operations: from preparing nuclear material for neutron irradiation in reactors to disposing or recycling of the irradiated material discharged from the reactor (Albright et al., 1997). The overall cycle is broadly called the nuclear fuel cycle. A series of manufacturing processes to prepare nuclear fuels constitutes the front-end of the nuclear fuel cycle (FNFC). The FNFC includes mining uranium ore, extracting uranium oxide (U3O8) from ore, called as milling. The U3O8 is converted to uranium dioxide (UO2) and then to uranium hexafluoride (UF6) to enrich the fissile material. UF6 is then converted back to UO2 at the concentration required to undergo fission and finally fuel elements with enriched UO2 are fabricated.

The back-end of the nuclear fuel cycle (BNFC) occurs with the extraction of spent nuclear fuel, i.e. namely the residue of nuclear fuel, from a nuclear reactor. The BNFC also comprises spent fuel cooling, storage, reprocessing, and waste disposal (KAERI, 2007; WNA, 2017a). Plutonium can be produced by reprocessing spent nuclear fuel. This recycled nuclear material can be used as an energy resource, typically in the form called MOX (mixed oxide) (KAERI, 2007). On the other hand, the plutonium could be used for military purposes rather than civilian ones. Therefore, its use is very sensitively linked to global politics. Figure 3 illustrates the causal relationships between the FNFC, nuclear power plants and BNFC.

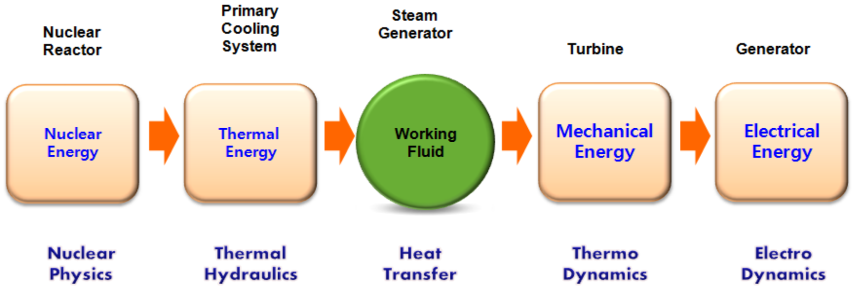


Figure 3 Process from nuclear energy to electrical energy (Kim, 2011b: 6)

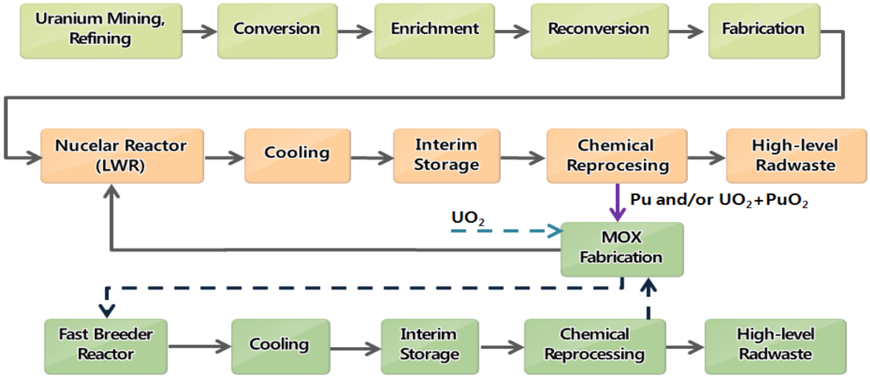


Figure 4 Nuclear fuel cycle for LWR and FBR (KAERI, 2007: 360)

A nuclear power system is among the most complex modern technologies. The central part of the nuclear power system, or the nuclear power plant (NPP) has a vast technical hierarchy that consists of hundreds of thousands of mechanical and electrical components, and of many different materials. For instance, a 1300 MWe-class nuclear power plant is made up with a large nuclear reactor structure, a pressure vessel and several steam generators. In addition, it needs about 350 heat exchangers, 200 tanks, 500 pump and compressors, 10,000 valves, 25 cranes, 30 transformer, 70 HV-motors, 550 LV-motors and 180 pieces of special equipment (Poneman, 1982). The more integration of disparate technologies is required, the more complex and difficult the organizational change involved (Walker et al., 1988). The characteristics of technical complexity may lead to knowledge intensity of a technical system, and in turn linked to its capital intensity, which affects the economics and safety of a nuclear power system. Regarding knowledge intensity, the nuclear power system needs to integrate a wide range of cutting-edge sciences and technologies in the fields of special materials and welding, safety and seismic design, and system integration.

Therefore, building up a nuclear technological innovation system can contribute to national knowledge-based manufacturing industries such as metallurgy, aircraft, electronics and shipbuilding industries. For instance, probabilistic safety assessment methodology could be applied to chemical industries. In addition, quality management processes accumulated in the course of creating a nuclear EIS could lead to improvement of the quality of goods and services in many other industries (KHNP, 2011). Hence, the introduction and development of nuclear power systems could directly and indirectly develop overall scientific and technological capabilities nationally and globally. A nuclear power system first produced electricity (albeit a trivial amount) in the

USA in December 1951 from a small experimental breeder reactor (EBR-1) (WNA, 2014). With the exception that uranium was discovered in 1789, scientific efforts over more than fifty years (from the late 1890s) gave rise to this noteworthy invention in the history of human civilization. Some remarkable steps in the process were marked by the discovery of ionizing radiation in 1895, radioactivity in 1896, neutrons in 1932, the first demonstration of atomic fission in 1938, the first experimental confirmation of the energy release from this fission about 200 million electron volts (MeV) in 1939 (WNA, 2014).

Regarding commercial production of electricity, in 1954 the world's first nuclear power reactor (AM-1) came on line with a net capacity of 5 MWe at Obninsk in the former USSR. Modified from a plutonium production reactor, the AM-1 reactor was water-cooled and graphite-moderated. This was followed by Calder Hall, the first four Magnox reactors with 50 MWe in the United Kingdom in 1956, and the first electricity-producing pressurized water reactor (PWR) with 60 MWe at Shippingport in the USA (OECD/NEA, 2008; WNA, 2014).

Over 60 years, nuclear power systems matured in such ways that they provided 10.6 % of the world's electricity with the generation of 2,490 TWh in 2016. As of 2017, there are 448 nuclear power reactors in operation with the total net capacity of 391.7 GWe in 30 countries and 57 more reactors are under construction in 15 countries (IAEA/PRIS, 2017). In addition to this quantitative diffusion, nuclear power systems have evolved qualitatively in terms of product innovation. The first-generation technical systems had small production capacities and were focused on realizing the commercialization of nuclear fission mechanisms to produce electricity until the early 1960s. It was natural to increase the capacity to improve economics when the so-called bandwagon effect took place in the second generation. The second-generation nuclear power systems still dominate the nuclear power market in the world. However, the nuclear accidents at Three Mile Island (TMI) in the USA in 1979 and in Chernobyl in the former USSR in 1986 led to the change of technological trajectories toward enhancing the safety of these systems along with their economics. From the early 1990s the third generation of nuclear power technical systems has been developed and commercialized in places including Europe, Korea, Japan, the United States, Russia and China, etc. while replacing the older technologies and meeting new market demand.

2. Organizational Change

Entrepreneurs, i.e. innovation actors, are assumed to optimize their behavior in generating and diffusing technological innovations in reasonably socio-economic ways while being influenced by change in external environments including relative prices and change in internal performance of innovations (Lundvall, 1985). Organizational change exists to manage entrepreneurial projects or enterprises to succeed in achieving technological innovations. According the US Project Management Institute (PMI) (quoted from KHNP (2011)), project management was defined as "the art of directing and coordinating human and material resources throughout the life of a project by using modern management techniques to achieve predetermined objectives of scope, cost, time, quality and participants satisfaction." Reflecting this definition in a more functional way, organizational change may be performed in terms of strategizing targets (directing objectives and coordination), organizing division of labor (coordinating human activities and material resources), resourcing inputs (securing resources), learning knowledge (securing resources), producing and marketing goods/services (achieving objectives), and obtaining public preference (achieving objectives). Most of these organizational elements are systematically interdependent in the enterprise. For example knowledge obtained from producing and marketing may feed learning while learning may change producing and marketing (Lundvall, 1985).

Entrepreneurs start innovation enterprises by exploring business opportunities and technical possibilities, a process that is called as strategizing in this paper. To the extent that organizational change is strategically well defined, strategizing can ensure that all the participants share a common understanding with respect to the 'means-ends chain' of a program and a project. Strategizing should identify the requirement for entrepreneurial competence and the ways to induce appropriate investments. Strategizing should set up individual targets of three core dimensions of the EIS such as organizational, technical and market changes, and make them systematically consistent to smoothly achieve the total goals of the entire projects concerned. This systematic consistency also contributes to reducing financial risks especially in capital-intensive technological enterprises such as developing nuclear power systems. Strategizing the innovation of a nuclear power system (NPS) may start with finding ways to allow it to cope with market needs. In general this process is carried out using a feasibility study during which total costs and benefits of the NPS provisional innovation project are evaluated for entire lifetime of the NPS. Assuming that technological innovations are highly specific to particular categories of industrial products and processes (Fransman, 1984; Bell and Pavitt, 1993), prior assessment of the current position of innovation competence or absorptive capacity is also required at this, the beginning of organizational change.

The complexity of coupling activities between technology, organization and market causes a substantial number of organizations to participate in the process of technological innovation (Hekkert & Negro, 2011). Organizing is done to create an organizational structure and its governance among participants during the entire process of the EIS. More specifically, it is the local and international division of labor between firms, research institutes, academic and industrial societies, and other stakeholders. Exchanging knowledge and other input resources is a key element of organizing activities that lead to learning-by-interacting and learning-by-using in networks. Due to the knowledge-intensive characteristics of the nuclear power system, the R&D organization, whether public or private, plays a very crucial role particularly in the first stage of technological innovation. In particular, national R&D is likely to provide a primary determinant of the building up of indigenous EISs in developing countries that are very likely to have limited absorptive capacity (Lee, 2004).

Resourcing is done to secure and mobilize appropriate inputs timely from outside for use inside the EIS. Not only financial and human capitals but also knowledge, technology and materials that are required should be input into all related activities in time. Appropriate resources should be allocated over the entire life cycle of the EIS to succeed in making new knowledge and technologies, and in turn, new goods and services, and new ways of organizational change (Hekkert et al., 2007; Markard et al., 2015). This organizational effort for resourcing can be analyzed by the availability against requirements of relevant resources at a given time. For example, working out an efficient financing package is critical for the success of such a capital-intensive innovation project as a NPS. The long-term duration and huge amount of capital investment for NPS learning and producing carry very high financial risk.

Learning is particularly concerned with obtaining knowledge and technology. It becomes the main channel to obtain, accumulate and improve knowledge and technology. Bell and Figueiredo (2012) mentioned that learning represents comprehensively all the ways that organizations “acquire knowledge, skills and other cognitive resources” (p18). As such, learning is prerequisite for creating and diffusing technological innovation. Through learning, entrepreneurs absorb external knowledge and technologies, adapt them to local circumstances and create indigenous knowledge and/or technologies. Codifying problems and solutions is an important competence of learning in the case of complex innovation systems. In the NPS project, several types of learning are combined, encompassing turnkey with the import of all knowledge, reverse engineering and localization under licensing contract, international venture, in-house R&D, etc. Research and development (R&D) represent one of the most important ways of learning particularly for knowledge intensive innovation. Educating and training of internal workers are also important channels of learning.

Producing is a routine process for making final deliverables in entrepreneurial innovations for transaction with users (Lundvall, 1985). In the case of NPS projects, producing is manufacturing and constructing nuclear power plants (NPPs) and other facilities. Manufacturing refers to making products such as parts, equipment, and subsystems of an NPS. Nuclear fuel, reactors, vessels, steam generators are examples of products. Construction is civil and architectural works, and installation of manufactured products to build nuclear power systems. As for NPPs, construction starts with the preparation of plant sites and ends with connecting new NPPs to a grid.

Marketing is an organizational function that results in a regular flow of goods and/or services from an entrepreneur or innovation producer to users via the market. It is the essential role of marketing that finds ways to stimulate the growth of the EIS to the extent that it is sustainably entrenched in markets and society while competing with or overthrowing incumbents. Thus, the role of marketing is to form markets for new goods and/or services created in the EIS and deliver them to users through the market. In the beginning, marketing should find targets (users) and identity their needs. Marketing may secure niches for the sustainability of the EIS, a target segment in an existing market, extend the set of users or create new demand where no market exists for new products or processes (Lundvall, 1985; Truffer et al., 2012). Marketing for NPS innovations starts with recognizing rationally the change of energy demand in terms of quantity and quality. Recently, the quality of energy takes into consideration not only economics, but also environmental and social compatibilities.

Socializing is to secure social legitimacy or preference that is given to innovation products outside the EIS. It is to influence the attitude of outside stakeholders in terms of their acceptance and desirability of innovation products or processes (Markard et al., 2015). While marketing is concerned with direct users of the EIS, socializing is to address a wider set of stakeholders who may be indirectly influenced by or who might affect the introduction and expansion of new goods and services. Socializing may be very helpful for exploiting new markets for the innovation outputs and for obtaining input resources while building legitimacy or a more favorable atmosphere for the EIS and counteracting the resistance of incumbent products and/or processes (Hekkert et al., 2011; Bergek et al., 2015). "Socializing can, for example take the form of delegitimation of rival technologies through organized lobbying work, as in the case of biofuels in the Netherlands, where proponents of second-generation biofuels actively tried to decrease legitimacy of first-generation biofuels." (Bergek et al., 2015: 55).

3. Technical Change

Technology is broadly defined as "the whole complex of knowledge, equipment, skills, competence, routines and practice which are necessary to produce a product" at laboratory to commercial scale (Rosenberg, 1982). Technology is linked to the science, which refers to the principles underlying natural or social mechanisms and phenomena. Technology is applying science to the socio-economic needs of human beings. As mentioned earlier in this paper, technological innovation is to synthesize technological or market knowledge, to create new products, processes and technological systems with the potential for creating new socio-economic value in human society. Most product innovations are followed by process innovations and further product innovations. New process technologies are introduced to adjust to new products. Competition between entrepreneurs who generate product innovations and the incumbents who dominate the existing markets gives rise to subsequent product and process innovations as they strive to gain competitive advantage in terms of product quality and production cost (Freeman, 1982). The central feature of technological innovation is the change of productive means, namely technologies. To put it another way, technological innovation is to create new socio-economic value by way of technical change.

The performance of technological innovation varies greatly with the contents and degree of technical change. The contents of technical change are concerned with the structure of a technical system. To be specific, the change of technical contents occurs in components and configurations which make up the technical structure. Components are parts or subsystems in the technical structure and configurations are the specific arrangements or patterns of components to make up the structure. As they systematically interact to perform technical functions, both components and configurations of technical structure determine the identity of a technical system. Therefore, technical change in a technical system occurs necessarily either its components or configurations at least, irrespective of the fact that the technical system is a product or a process.

The degree indicates how radically or incrementally technical change proceeds while directed by the so-called technological paradigm and trajectory. Empirical studies have showed that technical change has some common characteristic patterns in terms of degree. First, incremental technical change normally tends to follow technological 'trajectories that are usually defined by specific sets of technologies, i.e. knowledge and expertise within a technological paradigm. Second, major discontinuities (radical shifts) in technical change are related to change of the existing technological paradigm (Dosi, 1988). Schumpeter expressed a new set of radical innovations in generic technologies as “perennial gale of creative destruction” which was regarded as the root of economic growth (Schumpeter, 1942: 84). Elaborating the Kuhnian concept of scientific paradigm, Dosi (1982) conceptualized technological trajectory and technological paradigm. A technological paradigm is defined as a “model and a pattern of solution of selected technological problems based on selected principles derived from natural sciences and on selected material technologies.” (Dosi, 1982: 152). A technological paradigm represents cognitive frames shared collectively by the community of practitioners such as engineers, firms and technical societies, etc. in each particular activity. By a technological paradigm, a specific concept of technological progress is defined on the basis of its specific technical and socio-economic trade-offs (Dosi, 1982; Cimoli and Dosi, 1995). A technological trajectory is defined as the direction and pattern of technological progress within a technological paradigm. It denotes the improvement of multidimensional trade-offs of technological variables between technical and economic choices under an established technological paradigm (Dosi, 1982; Cimoli and Dosi, 1995; Utterback and Suarez, 1993). A technological trajectory comprises a single branch of technical design of a product or process evolved over time within a given technological paradigm (Hekkert et al., 2011). It is noteworthy that the prevailing technological paradigm and subordinate trajectories benefit from all kinds of evolutionary improvements in product quality and production costs, from a better understanding of market at the user side, and from a better handling of internal effort and external environments in terms of accumulated knowledge, capital outlays, infrastructure, available skills, production routines, social norms, regulations and lifestyles (Kepm, 1994; cited from Hekkert et al., 2007). Compared with technological paradigms, technological trajectories represent relatively minor technical changes (Utterback and Suarez, 1993). The change of technological trajectory gives rise to the incremental change in the current technical path. Thus, the degree of technical change is closely associated with the choice of technological trajectory and paradigm.

In line with this understanding, technological innovation can be interpreted as the process of searching, adopting, absorbing, adapting but also discovering, experimenting, developing and creating technological trajectories and paradigms. In other words, it creates new incremental and radical change of technology. The concept of technological paradigms and trajectories provides the basis of the degree of technical change. A technological paradigm determines the salient technical characteristics in the basic model of a technical artifact (product or process) and provides the basis for technological trajectories. That is to say, a technological paradigm defines the boundary of technological trajectories, i.e. multidimensional trade-offs among technological variables of the artifacts defined by each technological paradigm (Cimoli and Dosi, 1995). In this sense, the change of a technological paradigm creates a disjunction, or discontinuity of technical change from its current path, which is called as radical change. Freeman and Perez (1988) classified technological innovation in four levels.

At the first level, incremental innovation takes the bottom place in their typology. They noted that incremental innovations in general, take place continuously in any industry. Second, radical innovations are referred to as technological discontinuities so as to overthrow existing firms and industries but also create new markets and industries. Third, the change of technology systems results from the combination of radical and incremental innovation, which, together with organizational change, can affect existing industries and create entirely new sectors. Last, but greatest, the change of the techno-economic paradigm is associated with general-purpose technologies (e.g. steam, iron, electricity, internal combustion, ICT), which can affect the entire economic system through the change of general conditions of production and distribution (Freeman and Perez, 1988; cited by OECD/CSTP, 2013). Hence, understanding technical change is crucial to analyzing technological innovation systems using whatever approach, such as NIS, SIS, TIS and EIS. This provides the relationship between emerging technologies and incumbent ones in terms of process efficiency and/or product quality.

In the NPS industry, the emergence of nuclear fast breeder reactors is associated with the technological paradigm. Using new components such as fast neutrons instead of the thermal ones used in conventional nuclear fission reactors gives rise to change in the fundamental scientific principles needed to develop, produce and operate the NPS, and generate electricity. On the other hand, technological trajectories correspond to various types of nuclear power plants based on the same technological paradigms. In other words, technological trajectories refer to improving product performance involving such as economics, environmental compatibility and the potential of military abuse, etc. for example, under the existing thermal-neutron paradigm. The current nuclear power plants have evolved to increase plant capacity because of economics. The NPS capacity above 600 MWe is known to be economically competitive. Larger scale plants have contributed to the centralization of the electricity grid system, while providing a technological trajectory for subsequent development of NPSs. However, large-scale centralized electricity generation systems provide unfavorable context for emerging EISs to develop smaller and decentralized power generation systems (Lee et al., 2007).

4. Market Change

All innovation system approaches are generally developed to analyze the mechanism for creating new economic systems at all levels, from micro to macro, as an interactive result of the development of new technical paths and organizational patterns (Metcalfe, 1994). Schumpeter conceptualized the so-called "perennial gale of creative destruction" as "the essential fact about capitalism" at the micro level and the roots of the long waves in economic growth in the macro one (Schumpeter, 1942: 83-84). He encapsulated the view that modern capitalism tended to internally change and redefine itself restlessly in arguing that this process of creative destruction "~incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates." (Schumpeter, 1942: 83-84). Thus, technical advance is an inherent feature of capitalism involving often the overthrow of old economic systems (Tushman & Nelson, 1990; Metcalfe, 1994; Carlsson & Stankiewicz, 1991).

At the micro level, market change is caused by the process of creating and then selecting variety. Economic change results mainly from increasing the number of technological innovations and in turn the variety of goods and services (quality) rather over time than the number of specific outputs (quantity). In this evolutionary economics, technological innovation is linked to the economy in two principal ways. First, technological innovation gives rise to the creation of a variety of goods and services in the economy. Economic evolution starts at the micro level where entrepreneurs create new products and production processes that induce new patterns of market competition. Second, the variety is subsequently reduced as successful variants are selected. The selection process determines the range of variety through competition between alternatives including new variants and the incumbents. It is during the selection process that technological innovations meet external business opportunities and are substantially introduced into the economy (Carlsson & Stankiewicz, 1991; Metcalfe, 1994). When the balance between creating and selecting variants takes place, the economy shows a high degree of adaptability and dynamic efficiency, thereby reducing costs over time (Carlsson & Stankiewicz, 1991; Metcalfe, 1994). This is how technological innovation creates socio-economic values. Markets play essential roles in the evolutionary process by creating competitive pressure. Technological innovation by new entrepreneurs creates and changes the variety in the market, which triggers the selection process. Market competition may be the most typical mechanism for selection as firms strive to be successful in the process. Market selection results in the entry of new technological innovations and their further growth with their own competitive advantages, remove unprofitable alternatives and changes the relative economic importance of surviving technologies (Metcalfe, 1994). Thus, markets play a role in technological innovation. Therefore, in this paper, the market is considered as an important internal element to the extent that entrepreneurial technical change creates the variety of goods and services, and thereby setting up the market selection process.

At the micro level, market change explains how an EIS dynamically gains and improves its competitive advantage in both domestic and global markets. This market performance is dynamically evaluated by the share of the EIS and its further growth in the existing market, or exploitation of new markets in the domestic and global markets. This paper understands market change in three aspects: creating, expanding and entering market. Market creation means that technical change performed by entrepreneurs introduces radically new alternatives into the economy and create new markets in the global sense, for example, mobile communication market in the late 20th century. Market expansion and entry usually occur with the incremental change of pre-existing goods or services. New technical alternatives increase the number of variant or the degree of variety in the existing markets, selections are made to adjust the increased variety to economic opportunities. Successful variants turn up as a result of competition between alternatives involving both new variants and incumbents. Market expansion is offering a good or service to a larger segment within an existing market or selling the same good or service to different markets with different demographic, psychographic or geographic customers (WFI, 2018). Market entry means that entrepreneurs get trading their deliverables of technical change and succeed in establishing a foothold to stabilize their market performance.

In the late 20th Century, the term "sustainable development" was coined as a new paradigm of human civilization. In 1987, the UN report titled 'Our Common Future' defined sustainable development as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (UNWCED, 1987: 54). Sustainable development is a process of change in which all human activities are made with the intention of achieving harmony and enhancing both current and future potential to meet human needs in terms of economic growth, environmental protection and social stability (UNWCED, 1987). By definition, sustainable development integrates environmental and social issues with the same priority as economic development. Sustainable development requires a change in the pattern of economic growth, to make it less material-intensive, more ecologically sound and more equitable in its impact. At the same time, it should sustain the stock of ecological capital, improve the distribution of income and reduce vulnerability to economic crises (UNWCED, 1987). "For instance, a hydropower project should not be seen merely as a way of producing more electricity; its effects upon the local environment and the livelihood of the local community must be included." (UNWCED, 1987: 63). From this perspective, environmental and social stresses resulting from economy-centered development are very likely to threaten back economic growth by putting increasing uncertainty in economic systems. Hence, sustainable development requires increasing productive potential, protecting natural ecological systems and ensuring social stability through relative equity among all human societies (UNWCED, 1987).

The exploitation and use of energy is closely related to sustainable development. First, energy is prerequisite for economic growth. All economic systems including public and private sectors such as residential, commercial, manufacturing, service and agricultural ones, etc. cannot be operated without energy services. Energy supply drives economic development by improving productivity and employment (IAEA et al., 2005). Second, energy services affect the natural environment. There are four types of environmental risks to be pointed out regarding the increasing concern for global society: global climate change, acidification, the pollution of air, water, soil, and the damage to the health of living things. Excessive use of fossil fuels has some unavoidable detrimental effects on global climate change, acidification and pollution of the natural environment (Modi et al., 2005). Various accidents in nuclear and other energy sectors negatively impact on the health of our natural ecology. In particular, excessive greenhouse gases (GHG), especially carbon dioxide (CO2), emissions induce global climate change. Last but not least, energy is indispensable for the conduct of daily human life, e.g. cooking, heating, transportation and powering appliances at home and in local communities. As such, energy has direct effects on freedom, equality and basic standards of living, all of which are fundamental to social stability (Modi et al., 2005).

This is why energy must be available at affordable prices, provided in ways that are environmentally compatible with convenient access and with appropriate quality and quantity appropriate to support sustainable development. This dependable energy supply needs to be used to foster economic development, to avoid environmental calamities like climate change and to provide enough energy for the basic needs of society.

Like other energy systems, nuclear power systems are now inexorably linked to the paradigm of sustainable development. Nuclear energy resources bear high energy density, namely high specific energy potential (energy potential per unit fuel mass). As a primary energy source, one gram of fissionable material produces about three million times as much energy as one gram of carbon from coal. Even in reality, the operation of a 1000 MWe nuclear power plant for a year expends only about 18 tons of low enriched uranium. This is equivalent to some 1.1 million tons of LNG, some 1.5 million tons of oil or some 2.2 million tons of bituminous coal (KHNP, 2011; OECD/NEA, 2008). One ton of nuclear fuel can replace approximately 120,000 tons of coal. Furthermore, nuclear power, based on recent technology, is economically competitive with costs largely overlapping those of natural gas and coal. The range of its leveled cost of electricity (LCOE) is between 30 and 80 US $/megawatt hour (MWh) at a 5% discount rate and between 40 and 120 US $/MWh at a 10% discount rate (IAEA, 2014). LCOE from renewable sources are declining but are still significantly higher than other energy systems in most countries. Throughout the life cycle, nuclear power systems produce negligible amounts of CO2 emission, i.e. 2~59 kg-CO2/MWh: nearly the same as that of hydropower. Natural gas and coal are known to emit 389 - 511 kg-CO2/MWh and 790 - 1182 kg-CO2/MWh, respectively. This is to say, if natural gas power plants displace the nuclear power plants currently operating all over the world, about 300 million tons of carbon will be added annually, causing about a five-percent increase of carbon emissions in relation to energy production (OECD/NEA, 2008) If nuclear power plants are replaced by the existing mix of fossil-fuel plants including coal, oil and gas, there will be an eight-percent increase of energy related carbon emission (OECD/NEA, 2008). Hence, growing concerns about climate change and volatile oil prices have thrust nuclear power systems back to the top of national policy agendas for sustainable development in many countries as the best providers of sustainable energy supply.

However, radiological hazard and proliferation risk are more or less unique to nuclear power systems and these issues influence their EISs. In the process of nuclear power generation, radioactive materials are naturally generated. The creation of radioactive products results from fission in the fuel elements. In the nuclear reactor, materials and coolants are bombarded with neutrons created from fission. Absorbing these neutrons, the atomic nuclei in many parts of the NPP come to be radioactive. Spent fuel discharged from a nuclear power reactor also contains radioactive fission products (KAERI, 2007). Radiation hazards are concerns about the risks from accidents at nuclear power systems. Nuclear radioactivity causes grave concern about risk to the health of all living things. Nuclear proliferation emanates from the possible misuse of nuclear material for non-peaceful purposes and is linked to the danger of terrorism and nuclear war. According to INFCE (1980) report, proliferation refers to "the misuse by a government of nuclear fuel cycle facilities, know-how or materials to assist in the acquisition, manufacture or storage of a nuclear weapon" (p125). The acquisition of sufficient amounts of fissile material with the required purity is the major source of nuclear proliferation. So far, no technical means have been put into practice by which the sensitive technologies and materials created in civil programs can be separated from military applications. Proliferation risk is investigated in terms of the accessibility of highly enriched uranium in the FNFC and plutonium in the BNFC. Nuclear proliferation is very likely to hamper the stability of social systems. Military or terrorist abuse of any energy system may break down the stability of social relations.

Through market change, technological innovations can and should play a positive role in sustainable development. Technological innovation may develop substitutes for naturally scarce raw materials but also could provide optimal solutions for economic performance and simultaneously protect the natural environment and improve social stability. Following the work of Schumpeter, first, the economics of technological innovation, or evolutionary economics, accepted technical change, through market change, as a main endogenous determinant of economic growth. Evolutionary economics describes that firms (actors) have different capabilities rather than the same perfect knowledge in using internal resources and meeting the conditions in external environments. Each firm (actor) is recognized to acquire costly knowledge and use creatively the knowledge in perceiving external opportunities and taking risks in different ways, which eventually give rise to economic growth. When entrepreneurial firms take opportunistic risks and succeed in seizing the opportunities, their success puts pressure on other firms to take risks by changing their production processes and product mix for their survival in the economic system. This kind of competition creates new business opportunities and eventually long-term economic growth (Carlsson & Stankiewicz, 1991). Second, the concerns for sustainable development guide innovation-system approaches toward integrating economic issues with environmental and social ones (Lundvall, 2007), Hekkert et al., 2011) "Directing the efforts of the innovation system toward solving crises in ecological and social terms may be necessary in order to avoid real "limits to growth". […] it is important to note that the workings of unhampered market forces may in the longer term erode the basis of economic growth." (Lundvall, 2007: 115). Taking into account the triple challenge that human society faces, hence, the entrepreneurial innovation system (EIS) framework in this paper attempts to explain how to stimulate technological innovations in such a way that they can bolster sustainable development, or how an EIS, through market change, can contribute to sustainable development. When the paradigm of sustainable development puts down roots deeply all over the world, these market performances are expected to reflect the costs and benefits of the EIS in terms of the three pillars of sustainable development much more than they are now.

V. External Environments of Nuclear EIS

1. Industrial Trend

As long as an entrepreneurial innovation system is defined on the basis of a specific technology, entrepreneurs should first monitor and cope with the trend and change of industrial businesses linked to the creation and evolution of the technology. An industry is defined as a group of business activities or firms that are engaged in the production or processing of similar products, i.e. goods or services. The name of the industry usually depends on the primary product that the businesses or the firms handle, for example banking, construction or electricity generation, etc. (Surbhi, 2016; Morris, 2016). Therefore, it is worthwhile to read the status and trend of local and global industry that are related to the creation and growth of the EISs of concern.

If the NPS industry already exists when entrepreneurs create new nuclear EISs, the incumbent NPSs may affect strongly the emerging EISs in their creation at first and the growth later (Bergek et al., 2015). Existing technological assets such as the technological paradigm and physical infrastructure shared by the incumbents can have particular impacts on entrepreneurial strategizing, i.e. searching for the goals and best path for technical, organizational and market changes. To put it another way, the context of the existing industry may lead new EISs to compete with the incumbents in the up-stream market to secure input resources and in the down-stream market for innovation performance. Like any other technical system, therefore, the structure and growth trend of the NPS industry should first be monitored and analyzed.

In particular, the global context of the NPS industry provides references: the goals and paths of the market, of the technical and organizational changes of new nuclear EISs. At first, the global NPS innovation cycle shows the evolution of contemporary cutting-edge NPS technologies around the world. The path of the global technical change can affect the pace, degree and direction of new EISs (Fransman, 1984; Najmabadi. and Lall, 1995; Kim, 1999). The so-called product life cycle (PLC) model can be used to understand the trend of the global NPS industry although the model has been criticized for not being applied to industries, especially with a wide range of variety in terms of products and demands, or with specialized user demand (Utterback, 1979; Nelson, 1998). The PLC model of Utterback and Abernathy (1975 & 1994) explains and distinguishes the three progressive stages of industrial development. The fluid phase starts with the first innovation product that turns up in the global market and ends with the emergence of a product of dominant design after fierce competition of alternatives between the incumbents (in case of existing markets), the pioneer and the second-tier products. In the second transitional phase, process innovation becomes more important than product development as the product design becomes significantly standardized. In the last specific phase, products are very mature and specified while process technologies are standardized, automated and operated by lower-skilled labor. In the late part of this phase no further innovation occurs in both product and process and the production process responds only to demand.

Regarding developing countries, the stage model distinguishes the trend of industrial development by stage from absorbing foreign technologies through adapting them to local circumstances to innovating new technologies in indigenous ways. The model has been criticized for ignoring feedback loops and iterative learning, which are typical in the innovation system framework, and for not sufficiently explaining patterns such as quantum jumps and stage overlaps that do not follow predetermined stages sequentially (Hekkert & Negro, 2011; Lee et al., 1988). However, thanks to the simplicity of the model, it has often been used in studies on technological innovation in developing countries at the level of industry, sector and country (Fransman, 1984; Enos and Park, 1988; Lee et al., 1988; Hobday, 1997, Kim, 1999). Absorption in the initial stage refers to the acquisition and understanding of the imported technologies. Absorbing foreign technologies goes as far as understanding the technological know-how and duplicative imitation of imported ones (Hobday, 1997; Gonsen, 1998; Kim, 1999). Adaptation refers to the modification of foreign technology to accommodate local capabilities, needs and environments. Likewise, it encompasses the supply of local inputs and the scaling-up and automation of production systems but also the integration of incremental improvements in process and product technologies (Reddy & Zhao, 1990).

Developing countries (DCs) might pursue the localization of foreign technology in this stage. In the last stage of innovation, new product and process technologies are developed using domestic indigenous capabilities. Developing countries may become able to carry out high-caliber technological activities including R&D of complex products that are close to the international technology frontier (Bell & Figueiredo, 2012)3. At this stage of innovation, furthermore domestic innovation capabilities may approach or exceed the international technical frontiers. Latecomers may generate emerging technology in the fluid stage and compete with advanced countries (ACs) (Kim, 1999).

Global market competition should be investigated in terms of the degree to which international competition might act as opportunity for or threat to new EISs. Because it is quite linked to international technology transfer from advanced suppliers to the recipients in DCs, global market competition may determine how easily DCs can acquire the foreign knowledge and technologies for their technological innovations. For example, global NPS market competition supported Korean entrepreneurs to develop indigenous NPS through international technology transfer from advanced vendors in the mid 1980s. In the wake of the nuclear accidents at TMI in 1979 and Chernobyl in 1986, the global NPS market was suffering from oversupply.

Some nuclear power countries including the US and European ones announced a reduction or suspension of NPS businesses. However, Korea did not give up the nuclear power option because of its increasing demand for electricity given the country's poor energy endowment. Foreign suppliers competed fiercely to capture the Korean market while providing technical information, patent licenses, classroom training (CRT), on-the-job training (OJT), R&D participation and consultation (KAERI, 2007; Kim, 2011a; Lee and Lee, 2016). This is how global NPS market competition offered a great opportunity for the Korean nuclear EIS.

Thanks to intrinsic technological identity, the NPS industry needs large and long-term commitment in its development. As such, nuclear EISs are influenced by national governments and international institutions concerned. Here, institution refers to ideologies, principles and guidelines at the highest level of

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[3] Bell & Figueiredo (2012: 21) refer this stage to advanced level of innovative activity in developing countries.

the organizations making decisions to handle relevant issues. Appropriate institutions render technological innovations more efficient by shaping the long-term behavior of the actors and by reducing uncertainties (Edquist, 1997; Najmabadi and Lall, 1995). Industry-related institutions include the basic structure of laws, regulations, treaties, agreements and plans to stimulate the development of a specific industry at the national and global levels. Nuclear EISs should consider such as local and global nuclear power generation plans, nuclear R&D programs, nuclear power regulations and nuclear non-proliferation treaties. For example, national nuclear regulation policy directly provides the legal basis for all activities of the nuclear EISs in the course of obtaining licenses for construction, operation, etc. Managing nuclear innovation systems also requires understanding international nuclear institutions. International nuclear policies may play more significant roles in DCs because nuclear EISs in developing countries are usually triggered by international technology diffusion from ACs. Under these arrangements, based on their domestic policies, ACs are very likely to use their strong bargaining positions in technological, economic and military terms when they are involved in technological innovations in DCs. Therefore, it is essential to identify the nature and the impacts of these international institutions. A representative example is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). After the NPT came into force in March 1970 with 97 signatory states, the regime of nuclear non-proliferation was formulated particularly to halt horizontal nuclear proliferation between nuclear weapon states (NWS)4 and non-nuclear weapon states (NNWS). This international nuclear non-proliferation institution was regarded as a kind of political bargain between international political intervention and international technology supplies. As such, the NPT may pose significant constraints on civilian activities of nuclear EISs (Lee and Yang, 2003).

2. Sectoral Trend

The economy is broken into sectors at its highest level, e.g. financial, energy, healthcare, and public sector. In turn, each sector is divided into industries. For instance, energy sector is comprised of nuclear power, renewable energies and alternatives, etc. Industries within a certain sector mostly work with similar or related products but also share common features such as production processes or operational activities (Surbhi, 2016; Morris, 2016). Therefore sectoral

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[4] In the NPT, the world was divided into two categories of states: Nuclear Weapon States (NWS) with nuclear weapons prior to 1967 and Non-Nuclear Weapon States (NNWS) without nuclear weapons: Ham, P.V. (1993), Managing Non-proliferation Regimes in the 1990s: Power, Politics and Policies, London: Pinter Publisher, 13.

contexts and trends are likely to influence on new EISs in terms of their technical, organizational and market changes. Because the NPS industry is clearly embedded in the energy sector, nuclear EISs are influenced by the local and global contexts of the energy sector. Taking into account this hierarchical structure, entrepreneurs should understand the trend of the industry in question and then keep their eyes on external environments at the level of sector. Sectoral contexts should be examined in relation to their compatibility with the industry and with the target EIS. For example, as a strategic asset, natural endowments in the energy sector, such as energy resource reserves, may determine the direction of technical and market changes of new nuclear EISs. Domestic energy security is closely linked to this factor. Energy security refers to the sufficiency and availability of domestic energy carriers for the long-term development of a nation. In the aftermath of the oil shocks of the 1970s, the issue of energy supply transcended other economic ones. In countries with high external energy dependency based on imported oil, such as Korea, Japan and France, nuclear power generation was given high priority to enhance national energy security. In addition to domestic reserves of fossil energy resources, natural endowments encompass the quantity and quality of geothermal, water, wind and solar energy. Because the amount of energy used to produce electricity relies heavily on domestic geographical and climate conditions, non-dispatchable electricity producers may experience substantial difficulty in responding to abrupt fluctuations in demand. As such, non-dispatchable sources such as wind or solar may require backup from dispatchable power sources like nuclear, fossil fuel or geothermal, which are able to come online or go offline very quickly when demand swings.

New nuclear EISs can compete with all incumbents and other emerging EISs with different technologies for market share within the same sector. In a context where the competitors are enhancing the competitiveness of their innovation systems, it will be difficult for new nuclear EISs to exploit a position in the existing market. On a global scale, the energy supply chain may impact on nuclear EISs. The energy supply chain is concerned with the volatility of price and the uncertainty of long-term supply. Linked to energy security, for example the energy supply chain in 1970s was a strong incentive for the diversification of energy resources into nuclear power systems especially for base-load electricity generation. Sector-level institutions also impact on both new EISs and the incumbents. For instance, the increasing trend of energy market liberalization may create or destroy markets and alter the path of technical change for new EIS and incumbents (Bergek et al., 2015). In 1992, President Bush signed a new energy policy bill to change the monopoly structure of the electricity wholesale market in the USA to free competition. In a few years, almost a half of the states including Pennsylvania, California and New York began to alleviate regulations for electricity sales at the level of the retail markets

(McNeill, 2001). The deregulations in the energy and electricity markets have affected the choice of energy resources and technologies. The purpose of deregulations lies in securing, for consumers, the greatest advantages of the market mechanism through increasing competition. The deregulation of the electricity market may have a great influence on investors and operators because their economic risk can be increased by deregulating tariffs. This kind of market deregulation is a threat to capital-intensive technologies such as nuclear power systems (Lee et al., 2007).

In addition, there has been an ongoing trend for autonomous choice of energy and self-supporting behavior in advanced countries with an attempt to expand rather decentralized and independent energy systems. Households in those countries sometimes can participate in the process of electricity supply while making direct choices for the method of electricity production. For example, they install photovoltaic panels on the roofs of their houses, and wind-power turbines in their backyards. The increasing trend for autonomous choice of decentralized electricity systems will likely cause the existing large-scale NPS in ACs and later around the world to experience unfavorable competition, but could provide small-sized nuclear power systems with favorable opportunities.

3. Sustainable Development Trend

Since the late 20th century, the paradigm of sustainable development has spread around the world and proven to be one of the most influential rules in global society. In June 1992, 178 governments adopted the United Nations Framework Convention on Climate Change (UNFCCC) as an international environmental treaty and Agenda 21 as a non-binding, voluntarily implemented action plan of the UNFCCC at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil. When it was enhanced in September 2015, the 70th UN General Assembly adopted the 2030 Agenda for Sustainable Development and the 17 Sustainable Development Goals (SDGs) of the Agenda, which officially came into force on January 2016 (UN, 2017). In December 2015, the 195 UNFCCC participating member states and the European Union reached consensus by adopting the 'Paris Agreement' to reduce greenhouse gas emissions at the conclusion of COP 21 (the 21st meeting of the Conference of the Parties). By the aforementioned definition, sustainable development is a process of change in which all human activities are intended to be in harmony and to enhance both current and future potential to meet human needs in terms of economic growth, environmental protection and social stability (UNWCED, 1987). In its role as an alternative way to produce energy, innovation in nuclear power systems is closely related to the three pillars of sustainable development.

First, economic growth expands the market for electricity generation, which in turn is more likely to provide a rationale to introduce and expand nuclear power systems, particularly in association with poor energy security. Electricity is the dominant form of modern energy carriers for energy services (Modi et al., 2005). Growing economies at national or global scale usually requires a great deal energy, in particular, affordable base-load electricity, which may offer conditions favorable for nuclear power systems. On the other hand, economic capabilities may also affect nuclear EISs. Because the development and expansion of nuclear power systems requires a huge amount of money for a relatively long time, the current size and future growth potential of domestic or global economy forms the basis of financial markets for nuclear EISs. For example, when introducing NPSs in the late 1960s, Korea wanted to construct two 600 MWe-class nuclear power plants (NPPs) as its first nuclear enterprise. Because the Korean economy was not robust enough at the time to finance both NPPs by itself, only one NPP was built. Furthermore, the trend of economic structure, i.e. types of engines for economic growth, tends to have a strong effect on nuclear EISs. When industries with higher energy intensity drive the economic development of a given geopolitical territory, the economy needs more energy to produce a unit economic product, e.g. gross domestic product (GDP). This economic circumstance may greatly benefit electricity generation systems, like an NPS, that can provide the economy with a secure energy supply. For example, from the early 1970s, Korea started growing its heavy and chemical industries for its economic development. Because this development relied on securing a stable and substantial supply of electricity, the Korean government introduced and built a series of NPSs.

When it comes to environmental protection, the change of domestic natural environments is likely to influence on energy innovation systems including nuclear EISs. Because the unique impacts made by each energy system on natural environments have become better understood, changes in natural environments, whether these are positive or negative, have been affecting energy systems in terms of technical and market changes. For example, Chinese traditional reliance on fossil energy for economic development and daily lives created air pollution at such concentrations that it has been estimated to cause the premature death of approximately 350,000-500,000 men (Saikawam, 2014). In response to this change of the natural environment, the Chinese government set up the 13th Five-Year Plan from 2016 in which non-fossil primary energy provisions, including nuclear energy, were expanded from 9.8 % in 2013 to 15 % by 2020 and 20 % by 2030 (WNA, 2017b).

Furthermore, the majority of scientific evidence indicates that the increasing concentration of greenhouse gases (GHGs), especially carbon dioxide (CO2), has been changing the climate system of the Earth. As a result, global mean surface temperatures have increased and continue to increase, sea levels are rising, rainfall patterns are changing and more extreme climate events are taking place. While finding ways to cope with the unprecedented threat of global climate change, global human society has agreed to expand global energy systems by using non- or low-carbon emissions instead of burning fossil fuels. For example, China pledged to increase its share of non-fossil fuels, including nuclear energy, of its primary energy consumption to about 20% for 2020 - 2030 when it submitted its Intended Nationally Determined Contribution (INDC) to the UN in June 2015 (WNA, 2017b).

A society represents a group of people characterized by similar patterns of relationships (social relations) between individuals and who share the same geographical territory, political authority, cultures and institutions (Wikipedia, 2017b). As for energy enterprises, entrepreneurs should be very interested in social structure and social relations. In sociology, social structure is concerned with regularities in social life patterned by a social entity with which human beings, or members of a society, interact and live. Thus, social structure tends to determine the primary characteristics of a social group (Wilterdink and Form, 2017).

As an example, the trend of urbanization may influence on patterns of energy supply and demand. This trend will require not only provision of adequate amount, but also electricity supply of appropriate stability. Therefore, the expansion of urbanization will create opportunities favorable for nuclear power generation. Current nuclear power systems, however, might continue to play a limited role in densely populated urban societies as long as they are linked to social concerns about their radiological hazard (Lee et al., 2007). Compared with social structure, social relations are more specifically focused on human behavior in a society. As a proxy of social relations, this paper concentrates on social attitudes that are regarded to reflect social cultures, practices and dominant discourses about serious subjects. Social attitude is related to the legitimization of energy supply and use in society (Bergek et al., 2015).

There is a good example of how social attitudes critically affected the formulation of the photovoltaic (PV) market in Germany. Citizen groups all over Germany concerted their efforts for a long period, which played a pivotal role in the development of the PV innovation systems and their markets in the country (Dewald and Truffer, 2011; cited by Bergek et al., 2015: 58). In the case of NPSs, the socio-economic value of nuclear power systems has been severely controversial after the 2011 Fukushima Daiichi nuclear disaster. The nuclear radiological hazard resulting from the NPS accident tends to outweigh the social attitudes in many countries of its benefits of affordable electricity generation and low CO2 emissions. Therefore, social attitudes for or against nuclear power systems embedded in the interests and ideologies of society can greatly influence on the creation and growth of nuclear EISs. Thus, social structure and social relations are likely to impact the shape of technological paradigms as well as the trajectories of nuclear EISs in specific territorial contexts.

4. Technological Innovation Trend

Technological innovation has been widely recognized as one of the critical elements causing socio-economic development, not only by improving the productivity of the existing capital and labor, but also by creating new goods and services. According to Mitchell (1999), technological advance was estimated to contribute to more than 50 % of the economic growth occurring over the last 50 years of the late 20th century, e.g. 50% of in the US for, 76% in France, 78% in West Germany, 73% in the UK and 55% in Japan. In the 21st century, the progress of technological innovation has gotten faster regarding technological life cycles and more various regarding the effectiveness of products and the efficiency of processes.

More important to the point is that technological innovations and their deliverables are making great improvement to human civilization on the whole. New technologies such as ICT (information and communication technology), BT (bio-technology) and NT (nano-technology) are expected to lead to new techno-economic paradigms of human civilization in the 21st century. Along with this trend, interdisciplinary interactions of sciences and technologies will increase the variety and the speed of technological innovation. This trend of technological innovations has already led domestically and globally to energy developments such as bio cells, fuel cells, new energy carriers (e.g. hydrogen), micro-power networks, small nuclear reactors and solar technologies. Thus, the general trend of technological innovation is concerned with comprehensive increase in the capabilities of the economy and the society as a whole. In particular, the overall intellectual capital accumulated by technological innovation plays a pivotal role in building up and upgrading technological innovation systems (Freeman, 1982).

As for complex science-based technologies, such as nuclear power systems, creating an EIS has a wide range of interactions with the other disciplines of science and technology within which the EIS is embedded. The NPSs are also influenced by these external developments of science and technology. Computerized devices and computing networks, through simulations and automatic supervision as well as their visualization capacity, have greatly improved the safety and operation efficiency of nuclear power plants and nuclear fuel cycle facilities. In this context, the capability of entrepreneurs to learn has become more important for the absorption and adaptation of a wide spectrum of new external knowledge. If global technological innovations support only competitors, or alternative energy technologies, they could become great barriers against nuclear EISs (Lee et al., 2007).

VI. Analytical Framework for the Entrepreneurial Innovation System

From the perspective of entrepreneurs rather than policy makers, this paper elaborates technological innovation systems (TISs) and presents an alternative framework. Despite a wide and increasing diffusion of the concept, the TIS approach has not reached common consensus yet in terms of system structure and operational process. It has been used in a variety of systems and accordingly described in various ways. First, the traditional TISs have been applied to different units of analysis, which hampers common consensus of TISs in terms of generic components and structure. Second, most of the TISs are developed and used for policy making. All technological innovations eventually rely on entrepreneurs no matter how policy supports or hinders, and this requires alternative approaches. Third, the policy-oriented frameworks do not make clear the boundary between focal TIS and external environments. For the purpose of entrepreneurs, the internal system where the actors have the authority should be separated from external environments. Last, conventional TIS frameworks are usually applied to meso and macro levels. So far as actor activities are concerned, the TISs should be narrowly focused on micro level.

In addition, typical characteristics of technological innovation are integrated when we develop an alternative approach, herein labeled the entrepreneurial innovation system (EIS). First, the EIS framework pays most attention to its systematic nature to couple technological opportunity and socio-economic needs. Second, it takes special notice of the uncertainty of using knowledge to identity current problems and solutions, and also of projecting these into the future. This emphasizes on the role of organizational change. Third, the evolutionary process of the EIS reflects the cumulative aspect of technological innovation. An EIS may cover a series of projects at least under the same entrepreneur and technological paradigm. Fourth, entrepreneurs play the most pivotal role in the entire evolution of an EIS. This is how the EISs become the bare seeds that might take root in a larger set of ISs: not only TISs but also SISs and NISs. Furthermore, this paper takes into account the recent trend of sustainable development that has been globally diffused and institutionalized enough to affect strongly and comprehensively the techno-economic paradigms, or landscapes of human civilization. Sustainable development requires changes in the patterns of economic growth, to make it less materially intensive, more ecologically sound and more socially equitable. Technological innovations can play a positive role in sustainable development, for example by developing substitute materials and finding optimal solutions to solve the triple challenge. The advent of sustainable development has motivated the direction of this paper toward innovation system approach that integrates environmental and social issues with economic growth.

Taken all aforementioned understanding together, this paper explores an appropriate method, which enables to better understand and design technological innovation systems (TISs) especially for entrepreneurs. At first technological innovation represents the process to couple science and technology with market by entrepreneurs under the uncertain external context over time. Following this notion, an entrepreneurial innovation system (EIS) is defined and conceptualized as the set of actor, technology and market of which dynamic interactions generate and diffuse technological innovations in a specific technology area under a particular external environment. The conceptual framework of the EIS consists of three pillars such as technical, market and organization changes, and their interactions on the basis of intrinsic technological identity, and external environments. In other words, starting with initial market position, i.e. absorptive asset at a given time, based on technological identity, the EIS operates technological innovation as a continuous interactive course between organizational, technical and the resultant market changes while responding to the change of external environment. Intrinsic and generic technological identity is embedded in most of elements and linkages in the entire evolution of the EIS. This alternative framework of TISs is empirically tested on the nuclear power system (NPS). Not only intrinsic features but also evolutionary aspects of the NPS are analyzed to develop and refine the analytical framework of the EIS while increasing its validity and reliability.

Technological identity is evaluated in two ways: technical and socio-economic characteristics. At first, technical characteristics refer to the intrinsic scientific and technical qualities of a technical system that is evaluated by technical structure and function. Technical structure describes what components and configurations constitute a technical system and how they are connected to each other. Technical complexity, knowledge intensity and technical novelty should be employed in analyzing technical characteristics. Technical complexity is determined using the number of disparate elements (e.g. knowledge, materials, components, parts, equipment and subsystems) that make up one technical system. Knowledge intensity denotes how much a technical system depends on the quality and quantity of intellectual capital in its life cycle. Technical novelty represents the progress of technical change during the life cycle of a technological innovation that is an integration of the R&D cycle and product life cycle. Technical function describes what a technical system does to achieve its goal and generally defined in two ways. Operational function concerns whether the technical behavior of a technical system performs as intended in its design or not. Purposive function means a relation between the effect of technical behavior and the designed goal of the technical system for users. Accordingly, it is associated with socio-economic characteristics of a technical system that should be evaluated by three aspects: engineering economics, environmental and social compatibility. Engineering economics of a technical system refers to the cost of entrepreneurial efforts to perform an EIS over its lifetime. Environmental compatibility can be evaluated by analyzing what kinds of environmental risk might occur and how much they cause benefit or harm to natural ecological systems in the entire course of an EIS, in particular living things including human beings. Under the paradigm of sustainable development, social compatibility is evaluated by the size and degree of effect made by an EIS on social stability.

Organizational change is used to manage and succeed in technological innovation project, or enterprises performed by entrepreneurs. In other words, organizational change denotes change in the managerial efforts of entrepreneur to achieve technological innovations. This paper presents seven organizational elements, or functions required for entrepreneurial enterprises.

Strategizing is used to optimize the business opportunities and technical possibilities that will guide the organizational functions. Organizing is used to provide organizational structures and governance among the actors. Resourcing is securing and mobilizing appropriate inputs and throughputs in timely fashion mostly from outside to the inside. Learning is the main channel by which to obtain, accumulate and improve knowledge and technology. Codifying problems and solutions is important in the performance of learning. Producing is the process for making intermediate and then final deliverables of innovations for transaction with users. Marketing is forming markets and delivering innovation results to users. Socializing is securing social legitimacy or preference outside the EIS for the innovation projects and products.

Technical change can be explained in terms of the contents and degree of technical change. The change of technical contents takes places in components and/or configurations which constitute technical structure of a technical system. Components are parts or subsystems of technical structure and configurations are specific arrangements or patterns of components to constitute technical structure. The degree of technical change has two types: radical or incremental changes. Radical change means the change in the base principle or material of a technical system which typically creates discontinuity in the current path of technical change. Incremental change is the change of a technological trajectory within the current technological paradigm.

Market change refers to gaining and improving of competitive advantages in the market resulting from entrepreneurial innovation at the micro level and contributing to sustainable development at the macro one, Micro-level market change defined within an EIS is dynamically evaluated by the share of the EIS and its further growth in the existing markets, or exploitation of new markets in the domestic and global markets. Market creation means that technical change performed by entrepreneurs introduces radically new alternatives into the economy and create new markets in the global sense. Market expansion is offering a good or service to a larger segment within an existing market or selling the same good or service to different markets with different demographic, psychographic or geographic customers (WFI, 2018). Market entry means that entrepreneurs get trading their deliverables of technical change and succeed in establishing a foothold to stabilize their market performance. Taking into account the recent trend of sustainable development, the analysis of market change should be complemented by the effects of the EIS on the economy, on nature and on the society. Induced by an entrepreneurial innovation system (EIS), these effects denote the contribution of the EIS to economic growth, environmental protection and social stability.

In monitoring and analyzing the effects of external environments on the EISs, it is to pay attention to changing trends from four aspects, such as industry, sector, sustainable development and technological innovation. The trends of industry and sector are specific to an EIS that would be created and located in this industry and sector. In contrast, the trends of sustainable development and technological innovation are handled comprehensively within a given geo-political boundary (e.g. local state, nation state, international and global region) and they are considered to have general effects not only on the target EIS but also on other TISs. An industry usually depends on its primary goods and services such as those that nuclear EISs create and improve. Therefore, entrepreneurs need to understand the evolutionary history and prospects of the NPS industry. The trend of an NPS industry should be checked by reviewing the direction of technical change, the competition of up- and down-stream markets within the industry, and organizational efforts of competitors and related domestic and international institutions (e.g. social rules). As long as the energy sector embraces the NPS industry within its hierarchy, its context and trend usually have influence on new nuclear EISs. In general, sectoral contexts should be examined in relation to their compatibility with the industry and the target EIS. Entrepreneurs should check how coherently and closely the trend of the energy sector is linked to the NPS industry at least in terms of the competition of down-stream markets at a given boundary. As for sustainable development, at first, the overall trend should be checked in terms of institutions. Entrepreneurs need to find out what kinds of institutions and how strongly such institutions are linked to the paradigm of sustainable development, and how this paradigm is formulated or is being formulated domestically and internationally. Another important consideration should be given to examination of individual changes in its subordinate components, such as economic growth, environmental protection and social stability. The change of economic growth and its trends should be investigated using unit economic product, such as gross domestic product (GDP), and growth rate of GDP, etc.

Entrepreneurs should check how significantly the natural environment has been changed and will be changed in air, land and water. Social change should be examined in relation to social structure and social relations including size and type of urbanization, demography, and social preferences. Moreover the critical causal relations of economic, environmental and social changes need to be also analyzed and projected. The general trend of technological innovations needs to be understood. At first, it should be necessary to investigate the sciences and technologies that are leading at present or that are expected to lead among overall technological innovations locally and globally in the future. It is also important to find out how significantly the results of the dominant technological innovations have affected or will affect the economy and the society. Their contributions need to be determined by examining the creation of new industries and sectors, growth and life extensions of incumbent industries and sectors. Furthermore, some technological innovations might affect the entire economy and society, and continue changing them for a relatively long time. Hence these great effects (i.e. change of techno-economic paradigms of human civilizations) should be carefully analyzed.

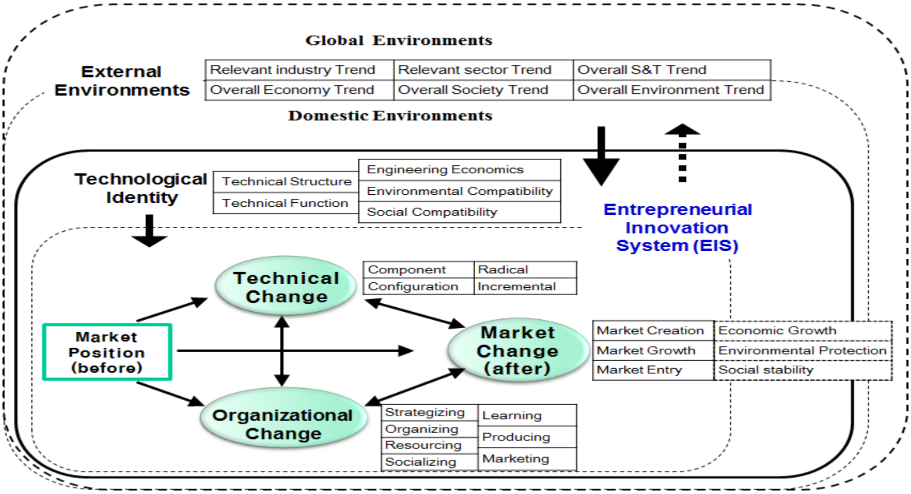

Figure 5 Analytical framework of EIS

Although the EIS is defined on the basis of a specific technology rather than a geographical territory, external environments are composed of domestic and global ones on the basis of national borders for the following reasons. First, a nuclear power system (NPS) is substantially regulated by a national authority, or by national policies and agencies for most of its innovations and operations. For instance, no new NPS technology can be produced and marketed without government permission in the form of such as design certificates, construction permits and operation licenses. Second, the complex and knowledge-intensive nature of an NPS requires that the culture, language and geopolitical system of the NPS be similar to that of the home country so that its technological innovations can be effective and efficient. The innovation system school lays out a logical basis to support the argument that historically, the nation state has determined technological learning and innovations during the last centuries (Lundvall, 1992). In addition, the school presumes that nation states differ in their cultural and political dimensions. Most countries usually have their own cultures, languages and socio-economic systems within a single geographical space, and under one political authority (Lundvall, 2016). When a country starts an innovative enterprise (particularly a complex and knowledge intensive one like an NPS), it is normal for entrepreneurs to search for business opportunities and technical possibilities first in their home country with which they are very familiar in terms of culture and geo-politics (Lundvall, 2016; Bergek et al., 2015). Taken together, the analytical framework of the EIS focused on a general nuclear power system was developed as seen in Figure 5.

VII. Conclusions and Implications

In this paper, an alternative framework is introduced and developed for the study of technological innovation systems (TISs). While accepting the increasingly wide diffusion of the concept, this paper starts by pointing out some criticisms of the traditional approaches to TISs. The conventional TIS approaches have included substantial variety in the level of analysis, have favored policy maker rather than entrepreneurs (actors) and have failed to clarify boundaries between internal systems and external environments. In addition, typical characteristics of technological innovations are articulated in developing the alternative approach while paying more attention to the systematic coupling between technical and socio-economic elements, the uncertainty of knowledge, the cumulative feature of their evolution and the base role of entrepreneurs for the success of TISs. Moreover, the recent trend toward sustainable development is incorporated because this regime has become globally diffused to affect strongly and comprehensively the techno-paradigm, or landscape of human civilizations. Considering this trend, the existing TIS approaches were modified to integrate economic dimensions with environmental and social ones. Taking all these matters into consideration, an entrepreneurial innovation system (EIS) is defined and conceptualized with five dimensions: technological identity, three core changes in terms of technology, organization and markets, and external environments. The conceptual framework is further elaborated with empirical analysis on nuclear power system in order to develop and refine the analytical framework.

In the technological innovation literature, it is widely accepted that the systematic management of technological innovation is a critical way to secure the competitive advantage of the industry concerned and in turn the overall economy. In other words, the school argues that technological changes should be explored to create the socio-economic value-added as much as it can by managing their causal connections to the related industries and the economy, and the external environments. In this respect, the approach in this paper first suggests an analytical framework for an entrepreneurial innovation system (EIS). As an empirical application to the nuclear power system (NPS), the argument is presented that the EIS framework is very useful to show how all the interactions of technical, organizational and market changes linked to an NPS could be systematically interconnected. The framework can also be used to illuminate the causal connections between the five core dimensions of the nuclear EIS and to their ultimate socio-economic value.

Bearing this understanding and result in mind, this EIS framework should be very useful for finding appropriate ways to connect coherently the NPS R&Ds and enterprises to its industry and in turn to the national socio-economy. Also useful be studies that pay more attention to organizational activities performed by entrepreneurs. This EIS approach could well be used for any entrepreneurs who want to create new innovation systems or to update their current systems in both developing and advanced countries. In addition, it could be used to manage technological innovations for other energy systems. The EIS framework proposed in this paper should be very helpful for designing and analyzing technological innovations in energy systems like NPSs that have complex and systematic relationships between the organizational, technical and market changes in consideration of their causal linkages with external environments. By including the paradigm of sustainable development, the framework could be used to link technological innovation of energy systems not only to industrial competitiveness and economic growth but also to environmental protection and social stability

The EIS developed in this study should be supplemented and enhanced with further study. First, each element of the EIS needs to be supported by finding subordinate measures that can extend its validity and reliability in more detail. The validity of subordinate measures concerns the rationale of the element that is central for measuring the effectiveness of the element for the purpose. Reliability represents the quality for the measure to produce the same result repeatedly. For example, contributions to the economy, natural environment and society at the macro level considered in this paper should have appropriate subproxies that should be able to show how much technological innovation systems achieved by entrepreneurs contribute to them in question. As for reliability, operational measures to check the progress and the performance of elements in the EIS should be identified to make the framework more reliable while taking into account specific characteristics of individual elements. Second, the EIS should be managed along with its entire life of evolution from creation to diffusion. The overall EIS should be explained in terms particular to the system boundary and analysis unit. The framework should answer how to explain the difference between generations of the EIS, from the first EIS to the second and in turn through subsequent ones. Last, the interactions between internal elements and the relationship between internal and external elements might vary with the progress of the focal EIS. Therefore, critical elements and linkages should be dynamically identified and ranked during its evolution, which should facilitate the design and management of the EIS from the perspective of entrepreneurs. Based on this understanding, it is worthwhile to develop appropriate procedures for entrepreneurs to design and run EISs from beginning to end. Whether they are employing top-down or bottom-up (market-pull or technology-push) approaches, the procedures must allow for the inclusion of feedback loops and interactive learning in a systematic way.

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