An Analytical Framework of Technological Innovation System: the case of nuclear power system

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Abstract – This paper is to elaborate and develop an alternative framework for the study of technological innovation systems. Compared 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. The so-called entrepreneurial innovation system is conceptually refined by synthesizing knowledge regarding technological innovation and innovation systems. On the basis of intrinsic technical characteristics for innovation, the entrepreneurial innovation system is composed of 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 that the innovation system is influenced by and copes with external environment in its evolution. On top of that, the framework of the entrepreneurial innovation system takes into account the recent trend of sustainable development particularly in the change of market and external environments. Technical and socio-economic characteristics of nuclear power system is empirically studied and integrated into the concept in order to articulate the analytical framework of the entrepreneurial innovation system. This analytical framework is expected to be very useful for technological innovations in other energy systems by reflecting their unique features.

Keyword: analytical framework, technological innovation, innovation systems, entrepreneurial innovation system, nuclear power generation

I. Introduction

From a perspective of technological innovation school which sees technological innovation as one of the critical element of economic development, this research tries to find out alternative approach which enables to show how to design ex-ante and analyze ex-post a technological innovation system with its dynamic process and performance. As technological change has been widely recognized as one of the primary engines causing economic growth, the so-called technological innovation system (TIS) approach has been developed to understand better technological innovations in a systematic way, namely the coherent linkages between technological change and economic growth while focusing on a specific field of technologies (Carlsson, 1994).

Despite a wide and increasing 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, its definition specifies broadly 'a specific technology area or field' allows various ways to describe various TISs involving different levels of analysis (Carlsson *et al.*, 2002; Truffer *et al.*, 2012) The framework has been applied to at least five different units of analysis such as a specific field of knowledge (e.g. as microwave engineering), a particular technology (e.g. biocompatible material), a product or an artifact (e.g. CNC machine tools), a product group or a set of related products and artifacts (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 the beginning the TIS has been supporting and gaining prominence in policy making (Carlsson *et al.*, 2002; Bergek *et al.*, 2015). As a branch of innovation systems, the TIS is also to heuristically analyze all societal subsystem, actors, 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 view of policy making and analysis, most of TIS studies typically highlighted the strength and weakness, the drivers and barriers, static structure and dynamic process of TISs (Hekkert *et al.*, 2011; Truffer *et al.*, 2012). The traditional literature hardly develops the framework more focusing on the actors than policy makers although they stresses very strongly that any innovation system never exist 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 TISs as a policy tool see that the frameworks can be strengthened more coherently by making the interactions between a TIS and its contexts explicitly in their concepts although they distinguish the internal system, called focal TIS and external contexts, as a policy tool, thus explicit consideration of external contexts (Bergek *et al.*, 2015). However, the EIS proposed in this paper considers that the focal TISs do not reciprocally interacted with external environments. The EIS is not authorized to directly control and address issues in external contexts. Instead the TIS open up possibilities of in such a way that the process and performance might change external environments. For example, the EIS can try and expect to gain government policy support and social legitimacy. The innovation performance of the EIS may result in external contexts as it diffuses widely deeply in general socio-economic system. However both external changes are beyond internal entrepreneurs' power.

Last, as long as actors' activities are much stressed in the system, the TIS should be narrow down to micro-level from meso-level which is typical in the traditional studies. The conventional TIS frameworks are usually limited to the meso-level studies, which are hardly applied to the micro-level systems (Markard *et al.*, 2015). However the micro-level studies should be incorporated into the meso-level in order to better understand the TIS more comprehensively (Markard *et al.*, 2015).

Bearing this understanding in mind, this paper is to explore an appropriate method which enables to better understand technological innovation systems (TISs) in entrepreneurs' sides, i.e. from a different angle of view of conventional literature. This opens up two research questions: how to differently analyze TIS from a perspective of entrepreneurs rather than policy makers; what should be changed for entrepreneurial innovation system from the TIS. By assembling some relevant theories regarding technological innovation and innovation systems at first, an entrepreneurial innovation system is defined and conceptualized. 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 as a case, this paper tests whether the analytical framework can be used for empirical studies in terms of its validity and reliability.

Thus this research is to explore an analytical approach for entrepreneurial innovation system (EIS) with its underpinning concept and elements. Chapter 1 provides the background to the research and introduces the objective and questions. It also outlines the analytical method including data collection and analysis as well as the thesis structure. Chapter 2 reviews traditional frameworks linked technological innovation and innovation systems, which is used to refine the concept of entrepreneurial innovation system (EIS) in chapter 3. The EIS is applied to nuclear power generation in chapter 4 and 5. Chapter 4 examines the internal elements of the system such as organizational change, technical change and market change based on technological characteristics while external environment in chapter 5. The results of empirical investigation are embedded to the EIS in chapter 6 which develops an analytical framework of EIS for the technological innovation of nuclear power system. Chapter 7 describes summery and 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 engine of industrial development (OECD, 1996; Kim, 1999), national economic growth (Rosenberg, 1982; Nelson & Winter, 1982). While creating the improvements in capital and labor productivity, the creation of new goods and services, technological innovation contributes significantly to the growth of industry concerned and overall economy in both developed and developing countries (Mitchell, 1999). The Schumpeterian and the neo-Schumpeterian view technical advancement as the central force in the economic phenomena, i.e. one of the endogenous determinants of economic development. However, the two are on the different perspective to see what kind of technological change contribute more significantly to economic growth. Schumpeter focuses on the radical change that refers to the deployment of discontinuity of radical innovation to expand the international technology frontier. The neo-Schumpeterian technological change is not so much of one major event resulting from an original breakthrough of radical innovation as an evolutionary process in which the incompleteness of the original breakthrough is successively improved by a series of complementary innovations (Kim, 1994). This neo-Schumpeterian viewed technological change as an evolutionary process of technically-diverse solutions and selection mechanisms to substitute for less-desirable technologies, in terms of cost advantages, technical superiority and evolutionary potential (Nelson and Winter, 1982; Arundel *et al.*, 1998). Although Schumpeter uses on radical innovation, 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'*, entrepreneurs as people who carry out enterprise, or innovation (Schumpeter, 1934: 65-67). 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 to carry out a new combination of productive means, realize commercially a new product, process or technological system, and created new socio-economic value added in the economy and the society (Schumpeter, 1934; Freeman, 1982).

Analytical frameworks of innovation systems were coined and conceptualized in 1980s. The earliest versions of innovation systems were created at the national level as a combination of two pioneers' perspectives, i.e. the SPRU (Science and Technology Policy Research Unit) at the University of Sussex in the United Kingdom and the IKE 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 which was reflected in Freeman (1982) where the national innovation system was coined with basic concept (Lundvall, 2016). The SPRU also explored the interaction between organizations participated in innovation processes in industrial enterprises a series of empirical projects (Lundvall, 2016). The IKE research on innovation, knowledge and economic dynamics brought about an innovation system approach which was developed by integrating evolutionary economics with the concept of 'national production systems (NPS)' used by French Marxist structuralists (Lundvall, 2016). Moreover scholars at the IKE paid particular attention to learning as well as innovation in production system in the process of user-producer interactions. Taken together, Lundvall (1985) presented an innovation system framework to better understand innovation and learning in production process while focusing on user-producer interfaces (Lundvall, 2016).

As referred to in Lundvall (2003 & 2016), Freeman (1982) coined 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 and Lundvall (1985) might be the first printed reference to the system of innovation, or innovation system (IS) with ISBN number as a booklet 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 focuses on 'ways in which competition is waged between firms and the measures taken by governments to help them' (Freeman 1982). Freeman (1982) approach began with accepting the idea that treats technology as an important element in changing market competition, which may be operated by appropriate policies at the level of both firm and nation-state (Freeman, 1982). Freeman (1982) attempted to explain why the NIS is so important for the international competitiveness of nations. It analyzed the influence of science and technology system on international competitiveness at the macro level while concerning in particular different ways of organizing an innovation system and its dynamic evolution over time at the micro level. Based on historical review, he argued that the way of organizing an innovation system was a dominant element in changing international technological leadership and in turn international competitiveness of firms and nations (Freeman, 1982). Freeman (1982) ends up with 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 who engages in different types of innovative activities and interacts tightly one another in learning and producing for innovation. The concept of innovation system is rooted in specific patterns of professional user (recipient) – producer (doner) relationships in the process of R&D and production for creating innovation (Lundvall, 1985). Lundvall (1985) linked the concept of innovation system to university-industry linkages and to user-producer interaction for product innovations at the micro level (Lundvall, 2016). In particular, Lundvall (1985) regards innovation as an interactive process where the role of users is very important for the development of new products and processes (Lundvall, 2016). Lundvall (1985) expands the concept of innovation system from micro to macro level as it brings the vertical integration of user-producer interactions crossing the traditional borders between sectors and industries (Lundvall, 1985). Lundvall (1985) 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 in order 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 national innovation system (NIS) and international trade performance while it emphasized that the NIS is based on systematic couplings between technology, entrepreneurial and market at the micro level. Lundvall (1985) viewed an innovation created and diffused by an interaction between user and producer at the micro level, which is expanded to the national level by introducing the vertical integration (Lundvall, 2016). Nevertheless, it is worthwhile noting that the first two pioneers created the framework of national innovation system which contributed to understanding systematically the role of technological innovation in national economic performance in terms of international trading performance and economic growth (Lundvall, 2016). It is also recognized that the NIS framework is still valid even in the era of globalization in particular when technical opportunities and user needs are complex and technical change undergoes discontinuously and tacit knowledge are more dominant than codified one. In this circumstance, geographical, language and cultural distance beyond national borders will make the innovation operate much less effective and efficient (Lundvall, 1985)

However the complexity of the NIS and the expansion of globalization give rise to dispute over the generic nature of the framework (Metcalfe, 1994; Hekkert, et. al., 2007). It is reported that it is very difficult understanding the overall network of innovation systems at the national level due to the countless number of elements and their interactions including actors, technologies, knowledge, institutions, markets, and so on. Moreover as learning of knowledge and user-supplier links are getting more international, which leads to increase international collaboration between actors in their innovation projects (Metcalfe, 1994; Hekkert, *et. al.*, 2007). According to Lundvall (2007), since 1990s, several new concepts of innovation systems have been developed. Swedish scholars such as Bo Carlsson and his colleagues presented the concept of technological system (Carlsson, 1994; Carlsson and Stankiewicz, 1991) and Franco Malerba with colleagues conceptualized the sectorial innovation system (SIS) (Breschi and Malerba, 1997; Malerba, 2002). They found that 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 innovation system rather than national boundary (Metcalfe, 1994). Although much room still remains for improvement, these concepts supporting specific technology and sectors have been gaining ground.

The sectorial 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). The concept of SIS attempts 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 coorperation 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 the 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 in not only the innovation structure and boundary of a sector but also the difference of performance of firms and countries in a sector in question (Malerba, 2002).

Carlsson and Stankiewicz (1991) firstly expressed technological system as an alternative framework of innovation systems (ISs) (Truffer *et al.*, 2012) Carlsson and Stankiewicz (1991) highlighted that technological systems in a specific technology area is the essential driver 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 technology area 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 lead to new business opportunities and in turn economic development (Carlsson & Stankiewicz, 1991). Focusing on a specific technology area rather than territorial boundaries and sectoral dimensions, the TS could be influenced, namely facilitated or impeded by some of national elements such as cultural, linguistics and other socio-political circumstances (Carlson, 1994), and by some of sectoral elements such as societal functions of sectors, competitions between technological fields within each sectors, etc. This special framework of innovation systems approach contributes to reducing the complexity of the NIS and SIS, and enabling the analysis of innovation systems whish attempt to better understand the coherent linkage technical change to economic development as comprehensive and systematic as reasonably possible (Carlsson & Stankiewicz, 1991; Hekkert, *et. al.*, 2007)

Since the inception, the TIS framework has shown some refinements. One of the significant is that it becomes to pay more attention to emerging technologies as well as to incumbent ones (Hekkert & Negro, 2011; Markard *et al.*, 2015). The original version of TS was pointed out that it places more emphasis 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 been used to analyze an innovation system of specific emerging technology and compare it with the existing ones in terms of its structural network and dynamic process (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 TIS (Hekkert *et al.*, 2007; Hekkert *et al.*, 2011; Truffer *et al.*, 2012). While the framework stresses organizational activities called 'functions', understanding what kind of them support or hamper the smooth running of the system becomes to be essential for the success of innovation (Hekkert *et. al.*, 2007). Among organizational processes, some of them are particularly highlighted such as knowledge creation and diffusion, influence on the direction of the search, entrepreneurial experimentation, market formation, creation of legitimacy, resource mobilization, development of positive externalities (Truffer *et al.*, 2012).

Going through this elaboration, it seems that this framework was labeled from technological system (TS) technological innovation system (TIS) as the importance of creating technological innovation was more emphasized than before. According to Markard *et al.*, (2015) the term of TIS was coined in 2008. Since then, the term of technological innovation system (TIS) rather than technological system (TS) has been usually used to analyze and design the innovation of a specific technological field in terms of the structures and dynamic processes (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 taken up its theoretical position under 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 ordinary goods and services (Carlsson & Stankiewicz, 1991; Hekkert *et al.*, 2011).

III. Conceptual Framework of Entrepreneurial Innovation System

Keeping this understanding in mind, this paper attempts to develop an alternative framework of the TIS at the micro-level which highlights the role of entrepreneurs in the system. This framework is labeled as an entrepreneurial innovation system. An entrepreneurial innovation system (EIS) is defined as the set of actors, technology and market of which dynamic interactions generate and diffusion of technological innovation in a specific technology area under a particular external environment. This EIS approach takes root in the ground of the traditional TISs. Figure 1 illustrates the position of the EIS under the TIS which is related the sectoral and the national approaches. EISs are seeds taking roots in a larger set of ISs. This is how the EIS can be the bare essentials of TISs and furthermore any other conventional ISs including the SIS and the NIS. Second, as long as actors' activities are much stressed in the system, the TIS should be narrow down to the micro level from the meso level. The traditional TIS studies have contributed to better understand particularly the complex and dynamic mechanism of the emergence and growth of new industries, and hardly applied to the micro-level systems (Bergek *et al.*, 2015; Markard *et al.*, 2015). However the micro-level studies should be incorporated into the meso-level in order to better understand the TIS more comprehensively (Markard *et al.*, 2015). Third, in the EIS proposed in this paper, entrepreneurs not policy makers take the lead in the entire life of technological innovation at the micro, not meso and macro level. This EIS is not authorized to directly control and address issues in external contexts. The focal TISs do not reciprocally interacted with external environments. Instead the TIS open up possibilities of in such a way that the process and performance might change external environments. For example, the EIS can 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 be still outside the EIS because the system could not govern the changing process and plan a priori the changed results as the targets of the system.

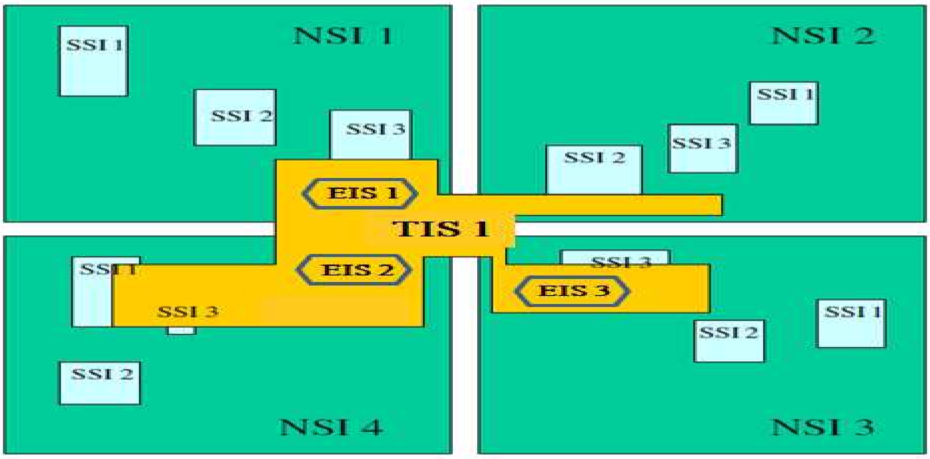

Figure 1 Relations between EIS, TIS, SIS and NIS (Hekkert *et. al.*, 2007: 417)
(Note) This figure is borrowed from Hekkert *et. al.* (2007) except that EISs is added by the author of this paper. In Hekkert *et. al.* (2007), moreover the TISs are labeled as technology specific innovation systems (TSIS) which is differentiated from the TS in view of the so-called large technical system (LTS). This paper regards the TSIS to be include in the TIS.

Following both Schumpeterian and neo-Schumpeterian perspectives, this 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 innovation requires to match 'to match new technical and scientific possibilities with the needs of potential users of the innovation'(Freeman, 1982) Whether it is based on scientific discovery, 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 inventions to users or customers through markets to gain socio-economic value added. *'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 regarding 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 the impossibility of accurate predictions of organizational terms such as cost, time and performance of technological innovation (Freeman, 1982; Dosi, 1988). What will be done and in turn achieved can hardly be known ex ant with any precision before the activities are carried out and the outcomes turn up (Dosi, 1988). *'If it is possible, then what is being done is not innovation.' (Freeman, 1982: 12).* In case of innovations are copied simply or improved incrementally, this uncertainty can be substantially reduced to speculate some of the problems and some of 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 with single event but a series of further innovates though incessant transformation as the band-wagon gets rolling (Freeman, 1982; Lundvall, 1985; Dosi, 1988) In particular cases of incremental changes, the state-of-the-art of the technologies developed and used already elsewhere tends to lead the trajectories of further innovation (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 then market change is the central feature of the TIS and this ability belongs totally to entrepreneurs. Putting it another way, entrepreneurs explore business opportunities, create technical change which expands market varieties and in turn concerted 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.

Taken all aforementioned features together, technological innovation refers to the process to couple technology with market by entrepreneurs under the uncertain context over time. In reflecting this notion in the definition, an entrepreneurial innovation system (EIS) is composed of five basic dimensions such as intrinsic technical characteristics of a specific technology field, the changes of technological, entrepreneurial organization, market and a wider set of domestic and global environment. Stressing the importance of sharing goal in a system over Fleck's concept (1992: 5),[1] the term of system is defined as a set of things connected interdependently and in orderly arrangement, so as to form a whole complex which works together with some reasonably and clearly defined overall function and goal. Therefore the five dimensions are interconnected to constitute an EIS. Figure 2 illustrates the concept of an EIS.

On the basis of intrinsic technical characteristics and initial market position, i.e. absorptive asset, at a given time, an EIS operates technological learning or innovation as a continuous interactive course between organizational change, technical change and the resultant market change while responding to the change of external environment. To be more specific, technical characteristics are concerned with intrinsic scientific and technical natures of technological system. The nature of technologies varies significantly between technology fields and industrial sectors, technical characteristics are likely to influence the ease or difficulty and the range of technological innovation (Pavitt, 1984; Dosi, 1988; Cohen and Levinthal, 1989; Carlsson, 1994). Besides, technical characteristics influence technical path while demanding different utilization and modification of the technology (Dahlman and Fonseca, 1987; Bell and Pavitt, 1993 & 1995). The technical characteristics also determines the managerial process in terms of the strategic position of TICs, the degree of linkages between organizations, way of learning, and investment of resources such as the cost and period of learning (Bell and Pavitt, 1995; Najmabadi and Lall, 1995; Gonsen, 1998). Thus, it is necessary to identify the underlying technical characteristics of a specific technology upon which technological change is very likely to depend (Cohen and Levinthal, 1989).

Technology complexity and knowledge intensity are among important factors in examining technical characteristics. Technology complexity refers to the number of disparate elements that require a technical system. Knowledge intensity is concerned with the importance of intellectual knowledge in a technical system, which may be compared with material intensity. Organizational change refers to the change of entrepreneurs' managerial efforts. Entrepreneurs' organizational activities are required to explore business opportunity, mobilize assets and then to solve problems in planning, doing and seeing technological learning and innovation (Teece, 2007; Teece and Pisano, 1994; Kim, 1999). The distinction between organizational change and technical change may be useful and important to better understand systemic causality of innovation system. How to form and run entrepreneurial organization may have a great deal of impact on the way of creating and diffusing technological innovation. Furthermore it is demonstrated in a series of empirical studies that organizational may change plays a key role in transforming technological

[1] "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)'

innovation to economic performance (Lundvall, 2007). Technical change refers to the change of technical path in the course of technological learning and innovation. Along with which technological paradigm and trajectory, technical path directs technical change toward market position (Dosi, 1982; Utterback and Suarez, 1993). Technical path, in particular technological trajectory is the pattern of improvement of multidimensional trade-off between technical and economic choices defined by each technology paradigm (Dosi, 1982; Cimoli and Dosi, 1995; Utterback and Suarez, 1993).[2] This trade-off is addressed to pursue the optimization between business opportunity and technical possibility through the efficiency of the production process or new product development, etc. Market change represents the change of market position resulted from entrepreneurial innovations. Going after its definition, technological innovation is completed in market. It is not too much to say that all of technical and organizational change exists only for creating socio-economic value added in the market of private and/or public sectors. As an ultimate performance of the 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 determent of industrial development and competitiveness (OECD, 1996; Kim, 1999), and national economic growth (Nelson and Winter, 1982; Mitchell, 1999) by improving the productivity of capital and labor and creating new products and services (Schumpeter, 1942). Through market change, technological innovation is extended to the intimate relationship between human civilization and technology progress by the increase of economic variety and production productivity. The change of market structure by technological innovation reflects that market is the linkage point where micro-level innovation systems is linked to macro ones.

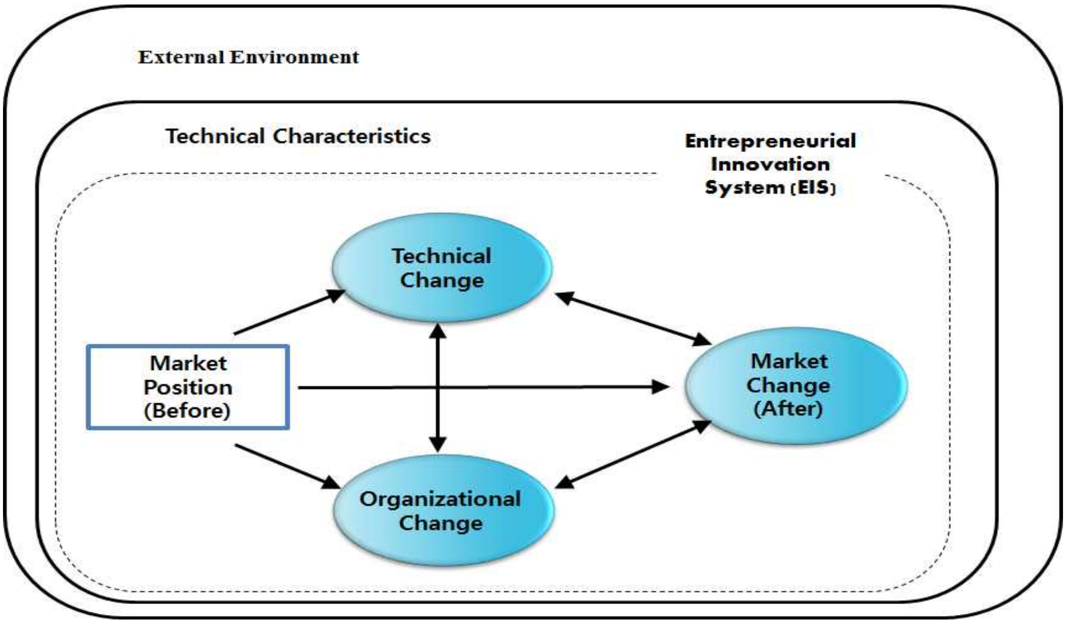

Figure 2 Conceptual Framework of an Entrepreneurial Innovation System

Strictly speaking, external environments in themselves are not within the EIS. However the EIS is linked to the environments to the extent that they impact significantly 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 organization's control, which directly and indirectly impact on the decisions and actions of an organization. There are generally two types of environments. The one is 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,

[2] Dosi (1982) defined technological paradigm as 'model and a pattern of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies'. In turn, he also defined technological trajectory as 'the pattern of normal problem solving activity on the grounds of a technological paradigm' (p 152).

monarchy), natural resources (water, forests, oil, coal. Soil), demographics (ages, genders, races, education levels represented in the work force) and cultural forces (values, langue, religious influences). Task environment (micro-environment) is the external forces that usually impact directly on organization's growth, success and survival. They are concerned with stakeholders (customers to clients, stockholders and labor unions), market competition of inputs and outputs, government policies, global and domestic technical change, etc.

IV. Entrepreneurial Innovation Systems of Nuclear Power Plant

1. Technical characteristics

When it comes to technical characteristics three aspects may stand out. They are technical complexity, knowledge intensity and technical novelty. Technical complexity is examined by the number of disparate elements such as knowledge, material, components, parts, equipment and subsystems, which all together comprise one technical system. This complexity could cause the difficulty of technological innovation in learning and producing new technical systems. The more complex technical change, the more difficult organizational effort is involved (Walker *et al.*, 1988). Knowledge intensity may explain how much knowledge strongly impacts on technological innovation in the entire life cycle. Knowledge intensity is the amount of organizational efforts to be made in the process of technological innovation. In other words, 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 may be required for the same amount of organizational activities. Besides, Technical novelty should be also counted to appropriately understand technical characteristics. Technical novelty refers to the progress of technological change. Technical novelty can be explained by the life cycle of technological innovation from its creation to its diffusion. Technological innovation is mainly created by research and development (R&D) and technological diffusion is usually related to the life of the product group including new and incumbent products. Therefore technical novelty can be examined by the cycle of R&D and product life. In case of technological learning in developing countries, it is particularly important to find out technical novelty in global sense. The path of global technical change is very likely to determine their choice of technologies to be imported and organizational ways to be mobilized for the learning (Fransman, 1984; Najmabadi. and Lall, 1995; Kim).
A nuclear power system refers to a system to convert nuclear energy to electric energy as seen in Figure 3 (Kim, 2011b). The primary energy form of atoms of uranium-235 is fissioned to produce nuclear energy which is transformed into thermal energy by heating primary system in the system. The heated fluid in the primary system is used to generate steam under high pressure which activates turbine generator. At last the turbine produces electricity. The electricity produced by NPPs is transmitted to electricity distribution grid systems (KAERI, 2007). The nuclear power system is composed of the set of chemical and physical operations from preparing nuclear material for neutronical irradiation in reactors and disposing of or recycling the irradiated material that is discharged from the reactor (Albright *et al.*, 1997). This cyclic nature is called broadly as the nuclear fuel cycle. A series of manufacturing processes to prepare nuclear fuels constitutes the front-end of the nuclear fuel cycle (FNFC). It includes mining uranium ore and milling, conversion, enrichment, and fabricating fuel element. The back-end of the nuclear fuel cycle (BNFC) starts with discharging spent nuclear fuel, namely the residue of nuclear fuel in nuclear reactor. It also comprises spent fuel cooling, storage, reprocessing, and waste disposal (KAERI, 2007). The plutonium can be produced by reprocessing spent nuclear fuel. This nuclear can be reused as an energy resources, typically called MOX (mixed oxide) (KAERI, 2007). However the plutonium could be used for military purposes other than civilian ones, therefore its use are very sensitively linked to global politics. Figure 3 illustrates causal relationships between the FNFC, nuclear power plant and BNFC.

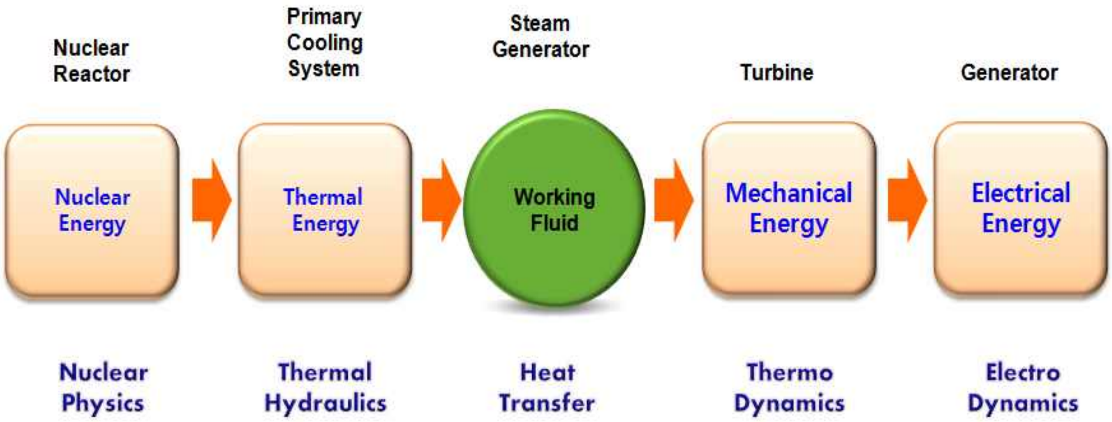

Figure 3 Process from nuclear energy to electrical energy (Kim, 2011b: 6)

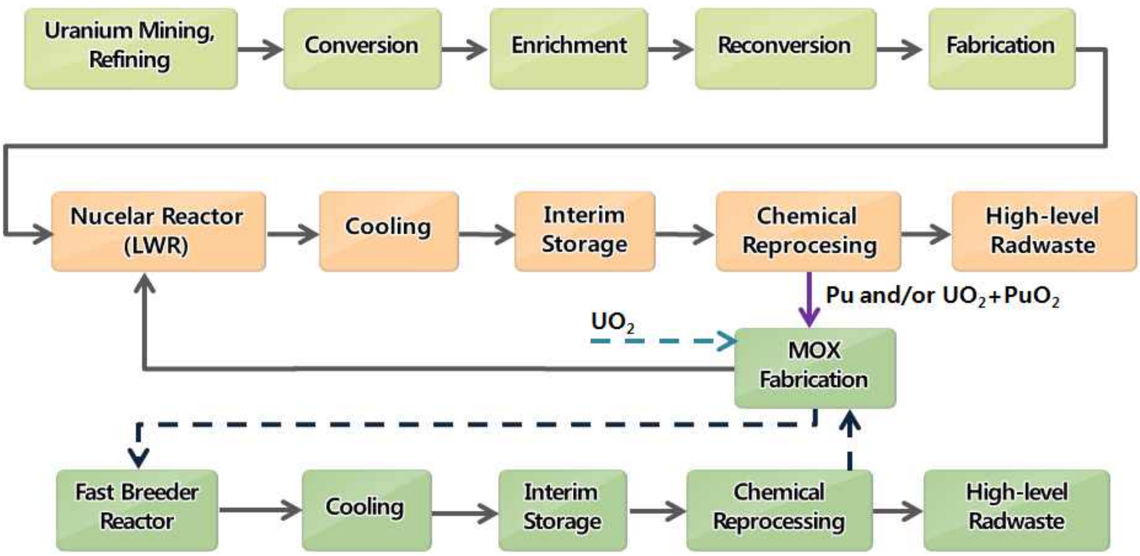

Figure 4 Schematic Nuclear Fuel Cycle for LWR and FBR (KAERI, 2007: 360)

A nuclear power system is among the most complex technologies. The central part of nuclear power system, or a nuclear power plant (NPP) has a vast of technology hierarchy that consists of hundreds of thousands of mechanical and electrical components, and materials. In addition to the enormous reactor structure, pressure vessels and steam generator, for instance a 1300 MWe, nuclear power plant needs about 350 Heat exchangers, 200 Tanks, 500 Pump and compressors, 10,000 Valves, 25 Cranes, 30 Transformer, 70 HV-motors, 550 LV-motors, 180 pieces of special equipment, etc. (Poneman, 1982). The more the integration of disparate technologies, the more complex and difficult the organizational process involved (Walker *et al.*, 1988). The characteristics of technical complexity may lead to knowledge intensity of product and production system, and in turn linked to capital intensity of them, which impacts economics and safety of nuclear power system. Regarding knowledge intensity, the nuclear power system needs to integrate a wide range of cutting-edge sciences and technologies in the field of special material and welding technologies, safety and seismic design technology, and system-integrated technology. Therefore, building-up nuclear TIS can contributes to national knowledge-based manufacturing industries such as metallurgy, aircraft, electronics and shipbuilding industries. For instance, the probabilistic safety assessment methodology could be applied to chemical industries. Besides, quality management process accumulated in the course of nuclear TIS building could lead the improvement of the quality of goods and services in many other industries (KHNP, 2011). Hence, the introduction and development of nuclear power system can directly and indirectly develop overall sciences and technologies capabilities of a country. Nuclear technological system firstly produced electricity (albeit a trivial amount) in the USA in December 1951. It was the was the small experimental breeder reactor (EBR-1) (WNA, 2014) Except the discovery of uranium in 1789, scientific efforts over more than fifty years from the late 1890s gave rise to this noticeable invention in the history of human civilization. Some of remarkable progress were marked in the discovery of ionising radiation in 1895, radioactivity in 1896, neutron in 1932, the first demonstration of atomic fission in 1938, the first experimental confirmation of the energy release from this fission as about 200 million electron volts in 1939 (WNA, 2014). For commercial production of electricity, in 1954 the world's first nuclear power reactor came on line a net capacity of 5 MWe at Obninsk in the former USSR. Modified from 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 system grew up in such a way that it 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 under construction in 15 countries (IAEA/PRIS, 2017). In addition to this quantitative diffusion, the nuclear power system has evolved qualitatively in terms of product innovation. The first generation of technical systems had small capacity of production while they are concentrated on commercial realization of nuclear fission mechanism to produce electricity until early 1960s. It was natural to increase the capacity to improve economics when the so-called band wagon effect took place in the second generation. The second generation of nuclear power system still dominates nuclear power market in the world. However, the nuclear accidents in 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 the system along with the economics. From the early 1990s this third generation of technical system has been developed and commercialized in Europe, Korea, Japan, the United States, Russia and China, etc. while replacing the old technologies and meeting new electricity demand.

2. Organizational Change

Entrepreneurs, i.e. innovation actors, are assumed to optimize their behavior in generating and diffusing technological innovations in reasonably economic ways while being influenced by change in external environment including relative prices and in internal performance of innovations (Lundvall, 1985). Organizational change is to manage entrepreneurial innovation projects, or enterprises in order to succeed in 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, organizational change should be performed in terms of strategizing targets, organizing division of labor, resourcing inputs, learning knowledge, producing and marketing goods/services, and obtaining public preference. Most of organizational elements are interdependent in the EIS. For example knowledge obtained from producing and marketing may feed learning while learning may change producing and marketing (Lundvall, 1985).

Entrepreneur starts an innovation enterprise with exploring business opportunities and technical possibilities, which is called as strategizing in this paper. To the extent that organizational change is strategically well-defined and effectively managed, strategizing can ensure all the participants share a common understanding with respect to the 'means-ends chain' of the program and the project. Strategizing should identify the requirement of entrepreneurs' 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 entire projects. This systematic consistency also contributes to reducing financial risks especially in capital-intensive technological enterprise such as developing nuclear power system. Strategizing nuclear power system (NPS) development is to find ways to make it to cope with market needs. In general this process is carried out with the so-called the feasibility study during which total costs and benefits of nuclear power generation for the entire life time are evaluated. Assuming that technological innovation is highly specific to particular categories of industrial products and processes (Fransman, 1984; Bell and Pavitt, 1993), prior assessment of absorptive capacity is also required at this beginning of organizational change.

The complexity of coupling process causes many organizations to be participated in the innovation project (Hekkert & Negro, 2011). Organizing is to make organizational structure and its governance among participants along the entire process of 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 exchange of information among actors, learning by interacting and learning by using in networks. Due to the knowledge-intensive characteristics of nuclear power system, R&D organization, whatever public or private, plays a very crucial role particularly in the first stage of nuclear power development. In particular national R&D is likely to provide a primary determinant of building up indigenous EIS in developing countries that are very likely to have limited absorptive capacity (Lee, 2004).

Resourcing is to secure and mobilize appropriate inputs in time from the outside to the inside of the EIS. Financial and human capitals, other input knowledge, technology and material are required necessarily to input into all activities of entrepreneurial innovation system. Appropriate resources should be allocated in the entire life cycle of the EIS in order to succeed in making new knowledge and technologies, new goods and services, and new ways of organization change (Hekkert *et al.*, 2007; Markard *et al.*, 2015). This effort of 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 NPP. Long-term period and huge-amount capital investment for NPP learning and producing carry very high financial risk.

Learning becomes the main channels to obtain, accumulate and improve knowledge and technology. As Bell and Figueiredo (2012) mentioned that learning represents comprehensively all ways of organizations to 'acquire knowledge, skills and other cognitive resources (p18)', which is prerequisite for creating and diffusing technological innovation. Through learning, entrepreneurs absorb external knowledge/technologies, adapt them to local circumstance and create indigenous knowledge/ technologies. Codifying problems and solutions is an important capability of learning in case of complex innovation systems. In the NPP 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) represents one of the most important learning particularly for the knowledge intensive innovation. Educating and training internal workers are also an important way of learning.

Producing is a routine process making final deliverables of innovations for transaction with users (Lundvall, 1985). In case of NPP project, producing is to manufacture and construct NPPs. Manufacturing refers to produce products such as parts, equipment, and subsystems of nuclear power plant. Nuclear fuel, reactor, vessel, steam generators are the examples of products. Manufacturing includes production process to produce such parts. Construction is to install nuclear power plants with related civil and architectural works. The construction of NPP starts with the preparation of NPP site and ends with connecting new NPPs into grid.

Marketing is an organizational process resulting in a causing a regular flow of goods and/or services from producer to user through 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 society while competing with or overthrowing the incumbents. Thus marketing is to form markets and deliver innovation results to users. In the beginning, marketing should find target in terms of users and identity their needs. Marketing should secure niches for the sustainability of the EIS, construct satisficing segment in the existing market, extend the set of users or create new demand where no market exist for new products or processes (Lundvall, 1985; Truffer *et al.*, 2012). Marketing for NPP innovations starts with finding the change of energy demand in terms of quantity and quality. Recently the quality of energy takes into consideration of economics but also environmentally friendliness and energy security.

Socializing is to secure social legitimation or preference given to innovation products outside the EIS. It is to influence the attitude of outside stakeholders in terms of their acceptance and desirability (Markard *et al.*, 2015). While marketing is concerned with direct users of the EIS, socializing is to address a wider set of stakeholder who may be indirectly influenced by or affect the introduction and expansion of new goods/services. Socializing is very helpful to exploit new market for innovation outputs and obtain input resources while building legitimacy or favorable atmosphere for the EIS and counteracting the resistance of the incumbents (Hekkert *et al.*, 2011). *'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' on a laboratory to commercial scale (Rosenberg, 1982). Linked to science which refers to underlying principles of natural or social mechanism and phenomena, technology is to apply science to socio-economic needs of human beings. Following aforementioned definitions and concepts, technological innovation is to synthesize technological or market knowledge and then to create new products and/or processes and technological systems carrying new socio-economic value in the economy and the society. 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 success of technological innovation relies greatly on the degree and direction of technical change. Empirical studies showed that technical change carries some common characteristics in the pattern in terms of degree of change. First, technical change normally tends to follow technological 'trajectories defined by specific sets of technologies, i.e. knowledge and expertise. Second, major discontinuities of technical change are related to the change of technological paradigm (Dosi, 1988). Elaborating the Kuhnian concept *of 'scientific paradigm (p 152)'*, Dosi (1982) conceptualized technological trajectory and technological paradigm. A technological paradigm is defined as 'a pattern of solution of selected technological problems based on selected principles derived from natural sciences and on selected material technologies (Dosi, 1982).' Technological paradigm represents cognitive frames shared collectively by the community of practitioners in each particular activity (engineers, firms and technical societies, etc.) (Cimoli and Dosi, 1995). A technological trajectory is defined as a pattern of technological progress, or the improvement of multidimensional trade-offs among technological variables under an established technological paradigm (Dosi, 1982:). A technological trajectory is a set of technologies that comprises a single branch of technical design of a product or process evolved over time along a technological paradigm (Hekkert *et al.*, 2011).

Technical change refers to the change of technical path throughout technological innovation. Technical path is explained by a combination of direction and degree. The direction means the place where technical change is involved and the degree shows how big technical change proceeds. The path of technical change is closely associated with technological trajectory and paradigm. It is worthwhile to note that the prevailing technological paradigm and subordinate trajectories benefit 'from all kinds of evolutionary improvements, in terms of costs and performance characteristics, from a better understanding at the user side, and from the adaptation of the socio-economic environment 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).

In line with this understating, technological innovation can be interpreted as the process of searching, adopting, absorbing, adapting but also discovering, experimenting, developing and creating technological trajectories and paradigms, namely incremental and radical change of technology. The concept of technological paradigm and trajectory provides the basis of the degree of technical change. A technological paradigm determines salient technological characteristics in the basic model of technical artifact (product or process) and provides the basis of technological trajectories. That is to say that technological paradigm defines the boundary of technological trajectories, i.e. multidimensional trade-offs among technological variables of the artifacts and systems defined by each technological paradigm (Cimoli and Dosi, 1995). In this sense, the change of technological paradigm creates the separation, or discontinuity of technical change from its current path, which is called as radical change. Schumpeter regarded a new set of radical innovations of generic technologies as *'perennial gale of creative destruction'* which is *'the essential fact about capitalism*' and the root of the so-called long waves in economic growth. He argued 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).*

Compared with technological paradigm, technological trajectories represent relatively minor technical changes (Utterback and Suarez, 1993). The change of technological trajectory gives rise to the incremental change of current technical path. Freeman and Perez (1988) classified technological innovation in four levels. At the first level, incremental innovation takes the place of bottom in their typology. They noted that incremental innovations in general take place continuously in any industry. Second, radical innovations are referred to 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).

When it comes to direction of technical change, it is necessary to understand product and process technologies. Product innovations are innovations with new goods and services addressed to meet the external needs of users separated from the entrepreneurs by a market (Lundvall, 1985; Afuah, 2003). Oriented to fulfill external users who are not satisfied by existing goods or services, product innovations comprise new materials, new process equipment, new consumer products and new services (Lundvall, 1988). Process innovations are the introductions of new elements into production or service operations to address the internal needs of the entrepreneurs (Lundvall, 1985) Process innovation occurs in input materials, task specifications, work and information flow mechanisms, and equipment used to produce a product or render a service (Afuah, 2003).

Most product innovations are followed by process innovations and further product innovations. New process technologies are introduced to adjust to new product. Competition between entrepreneurs who generates product innovations and the incumbents who dominates 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). It should be underlined that a process innovation of one side can be a product innovation of the other side. For example, if a company who succeeds in a process innovation and operates it for its own production lines is ordered to sell this process technology by 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).*

Hence, understanding technical change is crucial to analyze technological innovation system in whatever different approaches, such as NIS, SIS, TIS and EIS are involved. It provides the relationship between emerging technologies and incumbent one in terms of process efficiency but also product quality. The emergence of nuclear fast breeder reactors is associated with the technological paradigm. Using fast neutrons instead of thermal ones in the conventional nuclear fission reactor give rise to the change fundamentally scientific principle and technical concept for operating nuclear power systems and then generating electricity. On the other hand, technological trajectories corresponds to various types of nuclear power plants to improve performance of product quality, such as economics, safety and non-proliferation, for example under the existing thermal-neutron paradigm. In the basic models of nuclear power plant and nuclear fuel cycle systems are defined by a nuclear fission paradigm, such technological characteristics of nuclear power plant as economics, environmental friendliness and possibility of military abuse as well as complexity and radioactivity determine the path technological progress.

4. Market Change

All of innovation system approaches are generally developed to analyze the mechanism of creating new economic systems at all levels from micro to macro levels as an interactive result of the development of new technologies and organizational patterns (Metcalfe, 1994). Following Schumpeter's works, the economics of technological innovation, or the so-called evolutionary economics accepts technical change as a main endogenous determinant of economic growth. Schumpeter's concept of *'perennial gales of creative destruction'* encapsulated that modern capitalism tends to internally change and redefine itself restlessly. Thus technical advance is an inherent feature of the capitalism as often overthrowing old economic systems (Tushman & Nelson, 1990; Metcalfe, 1994; Carlsson & Stankiewicz, 1991).

In line with evolutionary economics, economic growth is caused by the process of creating and then selecting variety (Carlsson & Stankiewicz, 1991). Evolutionary economics sees that firms have different capabilities rather than perfect knowledge in using internal resources and meeting external environments. Each firm is recognized to acquire costly information and use creatively the information in perceiving external opportunities and taking risks in different ways, which give rise to eventually economic growth (Carlsson & Stankiewicz, 1991:98 & 100). When entrepreneurs take opportunistic risk and resultantly obtain the opportunities, their success puts pressure on other firms to take risks by changing the production process and product mix for their survival in the economic system. This kind of competition gives rise to new business opportunities and eventually long-term economic growth (Carlsson & Stankiewicz, 1991). Evolutionary economics starts at the micro level with the analysis about the process of technical and economic change including the role of entrepreneurs. In the evolutionary economics, technological innovation is linked to economy in two principal ways. First, technological innovation gives rise to creating variety of goods and services in the economy. Second, the variety is subsequently reduced as successful variants are selected (Carlsson & Stankiewicz, 1991). Putting it another way, technical change performed by entrepreneurs create new technical alternatives to be introduced into the market, which increase the number of variant or the degree of variety in the economy. The selection is made to adjust the increased variety to economic opportunities. Successful variants turn up as a result of competition between alternatives in including new variants and incumbents. When the balance between creating and selecting variants takes place, the economy shows a high degree of adaptability and dynamic efficiency, or reducing cost over time (Carlsson & Stankiewicz, 1991).

In this evolutionary economics, economic change results mainly from increasing the number of technological innovations and in turn the variety of goods and services qualitatively rather than the number of a specific output quantitatively over time. This is how technological innovation is the bare source of economic change (Carlsson & Stankiewicz, 1991). The selection process determines the range of variety through competition between alternatives including new variants and the incumbents. It is the selection process during which technological innovation meets external business opportunities and substantially introduced into the economy (Metcalfe, 1994). Market plays an essential role in the evolutionary process by creating competitive pressure (Carlsson & Stankiewicz, 1991). Technological innovation by new entrepreneurs creates and changes the variety in the market which triggers the selecting process. Market competition may be the most typical mechanism for the selection as firms strive to be adopted in the process. Market selection results in the entry of new technological innovations with their own competitive advantages, removes unprofitable alternatives and changing the relative economic importance of surviving technologies (Metcalfe, 1994). This is how market plays a role in technological innovation. Therefore this paper includes the market as an important internal element to the extent that entrepreneurial technical change creates variety and experiences the selection process in the market.

In the late 20th Century, the term of 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). Sustainable development is a process of change in which all of human activities attempt to be in harmony and enhance both current and future potential to meet human needs in terms of economy growth, environmental protection and social stability/equity (UNWCED, 1987). Since then, the paradigm of sustainable development has expanded 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. As it has been 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 1 January 2016 (UN, 2017). In December 2015, the 195 UNFCCC participating member states and the European Union reached consensus by adopting the so-called 'Paris Agreement' to reduce greenhouse gas emissions at the conclusion of COP 21 (the 21st meeting of the Conference of the Parties).

By the definition sustainable development integrates environmental and social issues at the same priority with 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 while sustaining the stock of ecological capital, improving the distribution of income and reducing the 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).* In this perspective, environmental and social stresses resulted from economy-centered development is very likely to threaten back economic growth by putting increasing uncertainty into the economic systems. Hence sustainable development requires increasing productive potential, protecting natural ecological systems and ensuring social stability/equity for all human societies (UNWCED, 1987). The concern of sustainable development directs the ISs approach toward integrating environmental and social issues with economic growth (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).* Technological innovations can play a positive role in the sustainable development by solving the triple challenge. Technological innovation may develop substitutes for naturally scarce raw material, to find optimal solutions to produce economic performance and simultaneously protect natural environment and improve social stability. In taking into account the triple challenge that human society face with, the EIS framework in this paper attempts to explain how to stimulate technological innovation in such a way that they can bolster sustainable development.

The exploitation and use of energy is closely related to the sustainable development. First, (energy economics) energy is prerequisite for economic growth. All of economic system from public to private sectors including residential, commercial, manufacturing, service and agriculture, etc. cannot be operated without energy services at all. Energy supply drives economic development by improving productivity and employment. (IAEA *et al.*, 2005). Second, energy services affect natural environment. There are four types of the environmental risks to be pointed out with increasing concern of global society. They are global climate change, acidification, the pollution of air, water, soil, and the damage to health of living things. Excessive use of fossil fuels has some unavoidable detrimental effects on global climate change, acidification and pollution of natural environment (Modi *et al.*, 2005). Various accidents in nuclear and other energy sectors negatively impacts on natural ecology. Last but not in the least, energy is indispensable for human daily lives, for example, cooking, heating, transporting and manufacturing or powering mechanical and electrical work, etc. (UNWCED, 1987:). As such, energy has a direct impact on freedom, equality and a basic standard of living which is instrumental to social stability. (Modi *et al.*, 2005). To support sustainable development, energy must be available at affordable prices, in environmentally friendly ways, in convenient access and in appropriate quantities. Thus dependable energy supply needs foster economic development and to avoid environmental calamities like climate change and to secure energy supply for social basic needs.

Like other energy systems, nuclear power system is 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 power plant for a year spends only some 18 tones of low enriched uranium, which is equivalent to some 1.1 million tons of LNG or some 1.5 million tons of oil, or some 2.2 million tons of bituminous (KHNP, 2011; OECD/NEA, 2008). A ton of nuclear fuel can replace approximately 120, 000 tons of coal. Furthermore, nuclear power is economically competitive with largely overlapping with natural gas, coal. The ranges of its levelized costs of electricity (LCOE) is between 30 and 80 $/megawatt hour (MWh) at a 5% discount rate and between 40 and 120 $/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 of countries. Throughout the life cycle, nuclear power system produces negligible amounts of CO2 emissions, i.e. 2~59 kg-CO2/MWh. This amount is nearly the same as hydro-power's. 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 gas power plants displace the nuclear power plant currently operating all over the world, about 300 million tons of carbon will be added annually, causing about a five-percent increase of the 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 concern of climate change and volatile oil price have thrust nuclear power back to the top of national policy agenda for the sustainable development in many countries. Nuclear power system has been increasingly recognized as a sustainable energy supplier. Radioactivity and proliferation risk can be more or less uniquely seen in nuclear power system. In the process of nuclear power generation, radioactive materials are naturally generated. The

creation of radioactive products results from the fission in the fuel elements. In the nuclear reactor, materials and coolant are bombarded by neutrons created from fission. Absorbing neutrons their nuclei become to have radioactivity. Spent fuel discharged from a nuclear power reactor also contains radioactive fission products (KAERI, 2007). Nuclear radioactivity causes grave concern of health risk of all living things. Proliferation risk emanates from the possible abuse of plutonium for the military purpose. 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 amount of fissile material with the required purity is the major source of nuclear proliferation. So far, no technical means have been put into practice to the extent that the sensitive technologies and material created in civil programs can be separated from military applications. Proliferation risk is investigated in terms of the accessibility of highly-enriched uranium in FNFC and plutonium in BNFC. Proliferation is linked to the risk of stability of social system. Military or terroristic abuse associated with any energy systems may break out social stability.
In sum, as market change reflects technical and organizational changes, domestic market exploitation and global trading performance should be priorly examined to explain how an EIS gains and changes its competitive advantage in both markets. These market performances represent the size and share of domestic and global markets taken by the EIS. Furthermore, taking into account aforementioned three aspects of sustainable development, market change may be caused by energy economics, environmental friendliness and social stability carried by an entrepreneurial innovation system (EIS). When the paradigm of sustainable development puts down roots deeply all over the world, these market performances are expected to reflect the cost and benefit of the EIS in terms of three pillars of sustainable development much more than now.

V. External Environments of Nuclear EIS

External environments should be grouped by national border especially in case of complex technology systems such as nuclear power plant. It is caused by the fact that NPS innovation and operation are mostly regulated by national policy and agency. For instance, any new product technology cannot be produced and marketed without government permission such design certificate, construction permit and operation license. In addition, the case of NPS innovation is very likely to comply with the idea of the NIS that takes into account a national border as the boundary of the system. The NIS scholars lay out logical basis to support their argument that historically the nation state has determined the stimulation technological learning and innovation during the last centuries (Lundvall, 1992). In addition, they presume that nation states differ in cultural and political dimensions (Lundvall, 2016). Most of countries usually have their own cultures, language and socio-economic system within one single geographical space under the one political authority (Lundvall, 2016). When they start innovation enterprises particularly in case of complex, noble and knowledge intensive ones liked NPS, therefore, it is quite normal for entrepreneurs to search for business opportunities and technical possibilities in their home country that are offered by cultural and geo-political dimensions (Lundvall, 2016; Bergek *et al.*, 2015). '~ *in the increasingly serious international confl icts, about which countries are paying for (the United States) and respectively appropriating benefi ts from (Japan) the investment in science and development of new technology, it is important to understand how diff erent and very diverse national systems work.' (Lundvall, 1992; 89).* [3] *'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).* Therefore external environments are divided into two types, or domestic and global ones according to the national border. Although the EIS is defined on the basis of a specific technology rather than a geographical territory, therefore external environments are decomposed of domestic and global one with the following reasons.

1. Domestic Environments

Domestic NPS context is related to the status of development of domestic NPS industry, and its position on the international technical leadership of NPS. If the domestic NPS context already exist when entrepreneurs create their EISs, this domestic NPS context may affect strongly nuclear EISs in their

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

creation and growth especially in searching for goal and path of technical, organizational and market change (Bergek *et al.*, 2015). The existing technological assets such as technological paradigm and physical infrastructure shared by the incumbent in the NPS industry can impact on the emergence and growth of new EISs. For instance, the current nuclear power plants have evolved to increase plant capacity because of economics. The capacity NPS is known to be economically competitive above 600 MWe. The large scale plants contributed to the electricity grid system to be centralized, which provided technological trajectory for subsequent development of NPSs. However, the large-scale and centralized electricity system may give rise to unfavorable context for emerging EISs to develop small-sized and decentralized power systems (Lee *et al.*, 2007). The current status and future growth of domestic NPS market impacts most directly on the creation and diffusion of nuclear EISs. This aspect is understood to be particularly important in case of complex technical systems in developing countries. Reflecting domestic economic growth, domestic market may provide signals for the size and direction of market change for EISs (Dahlman and Fonseca, 1987). Domestic market demand for nuclear TIS means the size and share of nuclear power system in domestic electricity market, which may be influenced by the competition between electricity supply systems including mainly fossil fuels and renewable energy resources. On the other hand, domestic context of NPS industry may obstruct the way of new EISs who must compete with the incumbent in up-stream market for input resources and in down-stream for market performance.

As the NPS industry is clearly imbedded in the energy sector, the nuclear EISs are influence by domestic sector context. At the national level, institution refers to ideologies, principles and guidelines in its highest level of country in decision making to handle national issues. The appropriate institution renders the technological innovation more efficient by shaping the long-term behavior of the actors and by reducing uncertainties (Edquist, 1997; Najmabadi and Lall, 1995). Sectoral-level institutions include the basic structure of laws, regulations, national plans, public organizations, and infrastructure to stimulating the development of a specific sector in the country. Sectoral contexts should be examined by their compatibility with EISs concerned. Government energy policy provides directly the legal basis for all activities of the nuclear EISs in the creation and diffusion of technological innovation such as construction and operation, securing safety, licensing construction and operation and international cooperation, etc. As a strategic asset, natural endowments in energy sector such as energy resource reserves may determine the direction of technical change and market change. Domestic energy security is closely linked to this factor. Energy security refers to the sufficiency and availability of domestic energy services for the nation's long-term development. In the aftermath of the oil shocks of the 1970s, the issue of energy supply transcended other economic ones in importance. In countries with high external energy dependency upon imported oil, such as Korea, Japan, France, etc., nuclear power generation was given high priority. In addition to domestic reserves of fossil energy resource reserves, natural endowments encompass the quantity and quality of wind and solar energy. As the amount of energy to be used to produce electricity heavily rely on domestic geographical and climate conditions, non-dispatchable electricity producers, they may experience substantial difficulty in responding to the abrupt fluctuation of demand. As such, non-dispatchable sources such as wind or solar may require backup from dispatchable power sources like nuclear, fossil fuels or geothermal. Nuclear power systems are dispatchable in coming online or going offline very quickly when demand swings. A new EIS can compete with the incumbents and other emerging EISs for market share in a sector. In a context where the competitors are increasing their competitiveness of innovation systems, it will be difficult for new EISs to exploit its position in the market.

Domestic economic growth expands the market for electricity generation which in turn provides one of the rationales to introduce and expand nuclear power system particularly in association with both poor energy security and rapid economic growth. In economic systems as well as at home, electricity is the bare and dominant form of modern energy carrier for energy services such as lighting, cooling, cooking, powering, communicating, manufacturing and so on (Modi *et al.*, 2005). Growing national economy requires usually a lot of energy, in particular electricity, which may contribute to the favorable conditions on nuclear power system. On the other hand, the size and growth potential of domestic economy may affect nuclear TISs while it may contributes to setting up financial market to be invested in such nuclear TIS businesses that require a huge amount of money for a relatively long time. This is how the current size and future growth potential of domestic economy lay the basis of the demand of nuclear TIS. Moreover, government economic policy has indirect but a great deal of effect over nuclear TIS, too. Nuclear power development carries a high investment risk with both high financial investment and low probability of returns in the short-term. Therefore national economic policy and capability contribute to reducing the uncertainty linked to the long-term investment of nuclear TIS.

Domestic innovation competence is concerned with comprehensive domestic potential to enhance absorptive capacity and innovation competitiveness based on scientific and technological systems. In particular domestic intellectual capital plays pivotal role in developing innovation systems as a whole (Freeman, 1982). When it comes to developing countries, domestic innovation competence is understood with the so-called stage model. The stage model distinguishes the progressive development of innovation competence by stage from absorbing foreign technologies, adapting them to local circumstances to innovating new technologies in an indigenous way. The model has been criticized for ignoring feedback loops and iterative learning which are typical in ISs framework for not sufficiently explaining those patterns such as quantum jumps and stage overlap that do not follow the predetermined stages sequentially (Hekkert & Negro, 2011; Lee *et al.*, 1988). However thanks to the very simplicity of the model, it has been used in a lot of studies on technological innovation in developing countries at the level of industry, sector but also country (Fransman, 1984; Enos and Park, 1988; Lee *et al.*, 1988; Hobday, 1997, Kim, 1999). First, absorption stage refers to the acquisition and understanding of the imported technologies. In the initial stage, absorbing foreign technologies goes as far as understanding technological know-how and duplicative imitation of imported technology (Hobday, 1997; Gonsen, 1998; Kim, 1999). Adaptation refers to the modification of foreign technology to accommodate local needs and environments, e.g. the supplies of local inputs and the scaling-up and automation of production systems, integrating incremental improvements in process and product technologies (Reddy & Zhao, 1990). Developing countries might pursue the localization of foreign technology. In the last stage of innovation, new product and process technologies are developed by domestic indigenous capabilities. The developing countries become to carry out high caliber of technological activities including R&Ds of complex products which are close to the international technology frontier (Bell & Figueiredo, 2012).[4] In this innovation stage, furthermore domestic innovation competence approach and go beyond the current frontier of international technological change. The latecomer may generate emerging technology in the fluid stage and compete with the advanced countries (Kim, 1999). As for complex science-based technologies, such as nuclear power system, creating an EIS has a wide range of interactions with other disciplines of science and technology in the country where the EIS is embedded.

Domestic social attitude refers to social norms and values for energy supply system as well as energy service in a country, which impacts on EISs in energy sector particularly in terms of legitimation (Bergek *et al.*, 2015). The social attitude impacts the shape of technological paradigm as well as trajectories of EISs in specific territorial contexts. As a proxy of domestic social attitude, this paper concentrates on social preference that is regarded to reflect social cultures, practices or dominant discourses about some serious subjects, etc. A recent study shows a good example by analyzing how photovoltaics market has been well formulated in Germany. The study showed that citizen groups all over the countries concerted their efforts for a long period, which played a pivotal role in the development of PV innovation systems and their markets in Germany (Dewald and Truffer, 2011; cited by Bergek *et al.*, 2015: 58). The unique and grave risk posed by the NPS to environmental and social aspects is likely to engender great concern in society as a whole. Therefor public understanding and acceptance embedded by the interest and ideologies of the society can greatly influence on the creation and growth of nuclear EISs.

2. Global Environments

Global context of NPS industry provides the reference of goals and paths of market, technical and organizational changes of new nuclear EISs. At first, global NPS innovation cycle shows the evolution of contemporary cutting-edge NPS technologies around the world. The path of the global technological change can affect the pace and content of new EISs (Fransman, 1984; Najmabadi. and Lall, 1995; Kim, 1999). The so-called Product Life Cycle (PLC) model can be used to investigate the trend of global NPS innovation cycle. Although the model is criticized for being not applied to industries, especially with a wide range of variety in terms of products and demands, or the specialized user demands (Utterback, 1979; Nelson, 1998). The PLC model of Utterback and Abernathy (1975 & 1994) explains and distinguishes the three progressive stages of the dynamic technological innovation mechanism. The first fluid phase starts with the first innovation product turned up in global market and ends with the emergence of dominant design of the product after fierce competition of product alternatives between the pioneer and the second-tiers. In the second transitional phase, process innovation becomes more important than product

[4] Bell & Figueiredo, (2012) refer this stage to ‘advanced’ level of innovative activity in developing countries (p 21)

development while product design becomes significantly standardized. In the last specific phase, products are very matured and specified while process technologies are standardized, automated and operated by lower-skilled labor. In the late of this phase no further innovation in both product and process occur and only process responds to demand. Global market competition of NPS industry is also important especially in the EISs in developing countries. It is quite linked to international technology transfer from advanced suppliers to the recipients in DCs and may determine how easily DCs can acquire the foreign knowledge and technology for their technological innovation. For example, in mid 1980s when Korea entrepreneurs attempted to develop indigenous NPS through international technology transfer from advanced vendors. Global NPS market competition supported the success of Korean nuclear EIS. In the wake of nuclear accidents at the TMI in 1979 and the Chernobyl in 1986, at the time global NPS market was suffering from oversupply. Some of nuclear power countries pronounced reducing or stopping NPS businesses including the US and European countries. However the energy-poor Korea did not give up nuclear power options generation because of its increasing electricity demands. Foreign suppliers competed fiercely one another to catch the Korean market, which provided great opportunity for the Korean nuclear EIS while providing technical information, patents license, classroom training (CRT) and on-the-job training (OJT), R&D participation and consultations. This was how global NPS market competition played a pivotal role in technological learning in nuclear EIS in Korea (KAERI, 2007; Kim, 2011a; Lee and Lee, 2016). Thus global market competition can be investigated in terms of the degree to which international competition might act as opportunity for or threat to new EISs.

The accessibility and availability of global energy supply chain is concerned with the volatility of price and the uncertainty of long-term supply. For example, the volatility of oil price and the uncertainty of its supplies in the future was a strong incentive for the diversification of energy resources and especially for base-load electricity generation. Global sector-level institutions also impact on both new EIS and the incumbents. For instance the increasing trend of market liberalization policies may create or destroy markets and alter the path of technical change for new EIS and the 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 into free competition. In a few years, almost a half of the states including Pennsylvania, California and NewYork began to alleviate the 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 the economic risk increases by deregulating tariffs. This market deregulation works as a threat factor for a capital-concentrated technology such as a nuclear energy system (Lee *et al.*, 2007).

New technologies such as ICT (information and communication technology), BT (bio-technology) and NT (nano-technology) are expected to lead new techno-economic paradigms of human civilization in the 21st century. Along with this trend, the interdisciplinary interactions of sciences and technologies will be increased to the variety and the speed of technological innovation. This global trend of technological innovations lead to the development of a bio cell, fuel cell, a new energy carrier like hydrogen, micro-power networks and a new generation's solar technology, etc. The NPSs are also influenced by these external developments of sciences and technologies. Computerized devices are largely applied in the nuclear industry. Computers and computing networks, through their simulation and automatic supervision as well as their visualization capacity, have improved the safety and operation efficiency of nuclear power plants and nuclear fuel cycle facilities. In this context, entrepreneurs' learning competence becomes more important to absorb and adapt a very wide set of external knowledge. If global technological innovations support competitors or alternative energy technologies, they would erect great barriers against nuclear EISs (Lee *et al.*, 2007).

This study pays attention to global trend of social attitude. It is due to the idea that social issues can go beyond one country especially in case of grave concern of nuclear accidents. This factor is investigated with the status and change of society's preference for nuclear power system in other countries, then how this foreign trend impacts on domestic social attitude for or against nuclear power system (NPS), which in turn contribute to the change of domestic supply and demand of NPS. In addition, there has been an ongoing trend for an autonomous choice of energy and a self-supporting behavior in advanced countries with an attempt to expand a rather decentralized and independent energy. Households in those countries sometimes participate in the process of electricity supply while making direct choices for the method of electricity production. For example, they install photo-voltaic panels on the roofs of their houses, and wind-power turbines in their backyards. The increasing preference for autonomous choice of decentralized electricity systems will cause the existing NPS in the countries and later around the world to experience unfavorable competition. Therefore the analytical framework of nuclear EISs needs examine how nuclear EISs are impacted by the global trend of autonomous and decentralized electricity supply systems.

Managing nuclear innovation system requires nuclear policies in foreign countries. Both developing countries (DCs) and advanced countries (ACs) can influence on global NPS industry in terms of technical and market changes. International nuclear politics plays more important role 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 position in technological, economic and military terms. Global political regimes surrounding nuclear power system (NPS) regulate technical change of NPS around the world in certain directions. Therefore it is of essence to identify the nature and the impacts of these international politics. Representative is international agreements on nuclear non-proliferation and on mitigating global warming. Both of them could affect the velocity of NPS. As the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) came into force in March 1970 with 97 signatory states, the regime on nuclear non-proliferation was formulated to particularly halt horizontal nuclear proliferation between nuclear weapon states (NWS)[5] and non-nuclear weapon states (NNWS). This international nuclear non-proliferation regime was regarded as a kind of political bargain between international political intervention and international technology supplies. Thus, the NPT regime may pose significant constraints on civilian activities of nuclear EISs (Lee and Yang, 2003). The way and amount of energy use affects global climate change. Excessive greenhouse gas (GHG), especially carbon dioxide (CO2), emission generates unavoidable detrimental effects on global climate change. The so-called Paris Agreement signed in December 2015 provides external opportunities for electricity generation systems with low CO2 intensity like NPS.

VI. Analytical Framework for Nuclear Power System

This paper elaborates technological innovation systems and presents an alternative framework for the study of innovation systems. Despite a wide and increasing diffusion of the concept, the TIS approach has not reached common consensus yet in terms of structure and process. It has been used in a variety of systems and accordingly described in various ways. First, the traditional TIS perspectives have been applied to different units of analysis, which hampers common consensus of the TIS in terms of generic components of its system structure. Second, most of the TISs are developed and used for policy making. All of technological innovations are totally rely on entrepreneurs no matter how policy supports or hinders, which requires alternative approaches. Third, the policy-oriented frameworks do not make clear boundary between focal TIS and external environments. For the purpose of entrepreneurs, the internal system and external environments should be separated, which shows where the actors have the authority. Last, conventional TIS frameworks are usually limited to the meso-level and macro studies. So far as actors' activities are much concerned, the TIS should be narrow down to micro-level. In addition, typical characteristics of technological innovation are clearly understood for the development of the alternative approach. This 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 knowledge in finding current problems and solutions but also predicting their future. Third, the cumulative aspect represents the evolution perspective of technological innovation. Fourth, entrepreneurs play the most pivotal role in the entire evolution of technological innovation. This is how the framework shows that the EIS becomes the bare seed which should take roots in a larger set of ISs such as not only TIS but also the SIS and the NIS.

In addition, this paper reflects the recent trend of sustainable development as it has been globally diffused and institutionalized, the regime becomes to affect strongly and comprehensively the so-called techno-paradigm, or landscape of human civilizations. Sustainable development requires a change in the pattern of economic growth, to make it less material-intensive, more ecologically-sound and more equitable. Technological innovations can play a positive role in the sustainable development by developing substitute material and finding optimal solutions to solve the triple challenge, etc. The advent of sustainable development directs the ISs approach toward integrating environmental and social issues with economic

[5] 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.

growth. As a result, the existing TIS approaches are modified to accommodate environmental and social dimensions as well as economic ones.

Taken all aforementioned understanding together, this paper explores an appropriate method which enables to better understand technological innovation systems (TISs) for entrepreneurs. At first technological innovation is noted as the process to couple technology with market by entrepreneurs under the uncertain context over time. Following this notion, an entrepreneurial innovation system is defined and conceptualized. An entrepreneurial innovation system (EIS) is defined as the set of actors, technology and market of which dynamic interactions generate and diffusion of technological innovation in a specific technology area under a particular external environment. The conceptual framework of the EIS consists of three core elements such as technical, market and organization changes and their interactions on the basis of intrinsic technological characteristics, and external environments. In other words, starting with initial market position, i.e. absorptive asset, at a given time, the EIS operates technological learning or innovation as a continuous interactive course between organizational change, technical change and the resultant market change while responding to the change of external environment. Intrinsic technical characteristics are embedded in most of elements and linkages in the entire evolution of the EIS. Furthermore, technical and socio-economic characteristics of nuclear power system (NPS) is empirically studied and integrated into the concept in order to articulate the analytical framework of the entrepreneurial innovation system. Not only intrinsic features but also evolutionary aspects are analyzed to develop and refine the analytical framework.

Technical characteristics represents intrinsic scientific and technical natures of technological system. Technology complexity and knowledge intensity are among important factors in examining technical characteristics. Technology complexity refers to Technical complexity is examined by the number of disparate elements such as knowledge, material, components, parts, equipment and subsystems, which all together comprise one technical system. Knowledge intensity denotes the quality and quantity of intellectual capital to be required in the process of technological innovation. Technical novelty represents the progress of technological change on innovation life cycles, integrated by R&D cycle and product life cycle. Organizational change is to manage entrepreneurial innovation projects, or enterprises in order to succeed in technological innovations. Organizational change denotes the change of entrepreneurs' managerial efforts in planning, doing and seeing technological learning and innovation. This paper presents seven organizational elements which are most required for entrepreneurial enterprises. Strategizing is to optimize business opportunities and technical possibilities which direct the other organizational functions. Organizing is to make organizational structure and its governance among participants. Resourcing is to secure and mobilize appropriate inputs in time from the outside to the inside. Learning becomes the main channels to obtain, accumulate and improve knowledge and technology. Codifying problems and solutions is an important in learning. Producing is a routine process making final deliverables of innovations for transaction with users. Marketing is to form markets and deliver innovation results to users. Socializing is to secure social legitimation or preference given to innovation products outside the EIS.

Technical change refers to the change of technical path throughout technological innovation. Technical path is explained by a combination of direction and degree. The direction means the place where technical change is involved, namely technical product or process. The degree of change shows how big technical change proceeds as it is decomposed into radical and incremental change. Product change is the change with new goods and services addressed to meet the external needs of users while process change is to introduce new elements into production or service operations to address the internal needs. The concept of technological paradigm and trajectory is employed to distinguish radical and incremental changes. Radical change means the change of technological paradigm which represent the bare principle and/or material of a technical system. The radical change gives rise to the discontinuity of technical change from its current path. Incremental change is the change of technological trajectory under the current technological paradigm. Market change represents the change of competitive advantages in the market in question resulted from entrepreneurial innovations. At first, the competitive advantage should be examined by domestic market exploitation and global trading performance of the nuclear EIS. These market performances represent the size and share of domestic and global markets taken by the EIS. Taking into account the recent trend of sustainable development, moreover the analysis of market change should be complemented by energy economics, environmental friendliness and social stability carried by an entrepreneurial innovation system (EIS).

Although the EIS is defined on the basis of a specific technology rather than a geographical territory, this paper classified external environments into domestic and global ones due to the following reasons. First, the nuclear power system (NPS) is substantially regulated by the national authority in most of its innovation processes. Second the complex, noble and knowledge-intensive nature of the NPS requires the same culture, language and geopolitical system of the home country for the effective and efficient process of technological innovations. Five factors linked to domestic environments include NPS industry, energy sector, economic growth, innovation competence and social attitude. Domestic NPS industry is related to the competition of up- and down-stream markets, its global competitiveness and government nuclear policies. Domestic energy industry is linked to in particularly the competition of down-stream markets and the related government policies. Domestic economic growth factor includes national economic policy and capability. Domestic innovation competence denotes comprehensive domestic potential to enhance absorptive capacity and innovation competitiveness based on scientific and technological systems. Domestic social attitude refers to social norms and values for energy supply system as well as energy service in a country, which impacts on EISs in energy sector particularly in terms of legitimation. Global environment should be analyzed with global NPS industry, energy sector, innovation trend, social attitude and international nuclear politics. Global NPS industry context represents global NPS innovation life cycle and global market competition of NPS industry. Global NPS innovation life cycle shows the evolution of contemporary cutting-edge NPS technologies around the world. The elements of global energy sector are the accessibility and availability of global energy supply chain which reflect the volatility of price and the uncertainty of long-term supply, and global sector-level institutions. Global innovation trend is linked to the entrepreneurial capabilities of learning. If global technological innovations support competitors or alternative energy technologies, they would erect great barriers against nuclear EISs. Global social attitude should be investigated with the status and change of society's preference for nuclear power system in other countries, then how this foreign trend impacts on domestic social attitude for or against nuclear power system (NPS). International nuclear politics represents global political regimes surrounding nuclear power system (NPS) regulate technical change of NPS around the world in certain directions. The analytical framework of nuclear EIS is developed as seen in Figure 5.

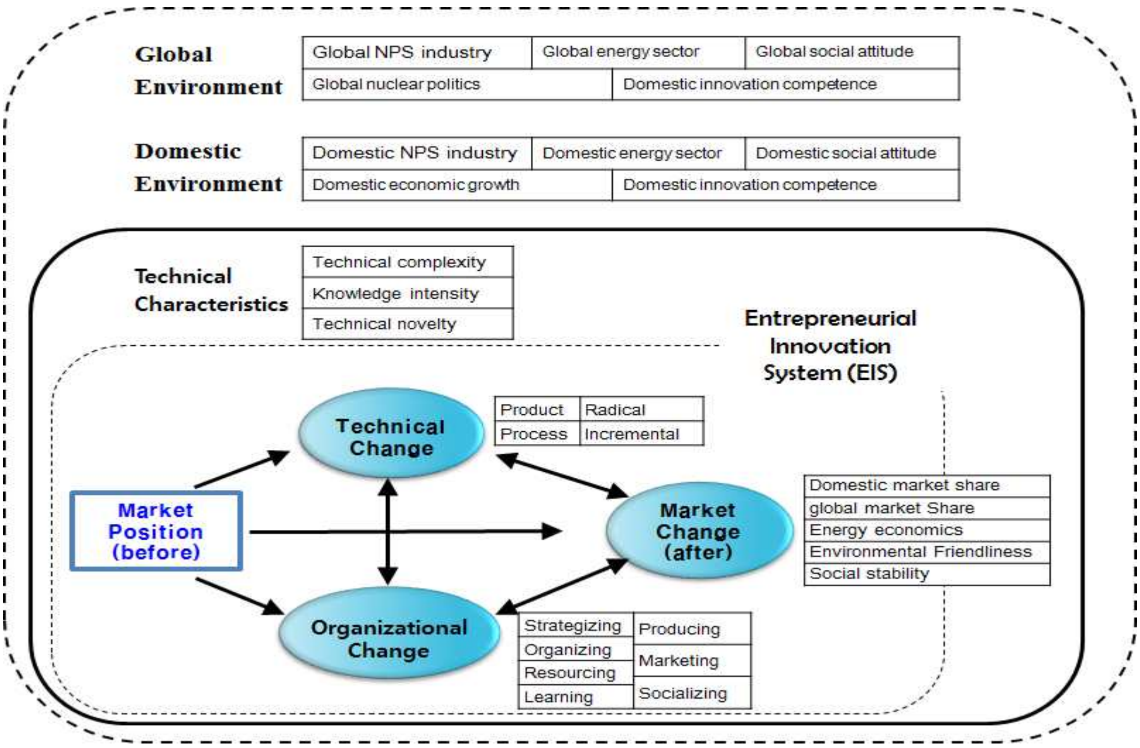

Figure 5 Analytical Framework of nuclear EIS

VII. Conclusions and Implications

This paper elaborates and presents an alternative framework for the study of technological innovation system (TIS). While accepting a wide and increasing diffusion of the concept, this paper starts with pointing out some critics on the traditional approaches of technological innovation systems (TIS) in terms of various levels of analysis, neglecting entrepreneur compared with policy maker, blurring boundary between internal systems and external environment. In addition, typical characteristics of technological innovation are clearly understood for the development of the alternative approach. This framework pays more attention to its systematic coupling of techno-economic elements, the uncertainty of knowledge, cumulative evolution and the bare role of entrepreneurs. Moreover, this paper reflects the recent trend of sustainable development. As it has been globally diffused and institutionalized, the regime becomes to affect strongly and comprehensively the so-called techno-paradigm, or landscape of human civilizations. As a result, the existing TIS approaches are modified to accommodate environmental and social dimensions as well as economic ones. Taken all aforementioned understanding together, this paper defines and conceptualized an entrepreneurial innovation system (EIS) with five dimensions, such as technical characteristics, three core changes in terms of technology, entrepreneur and market, and external environments. The conceptual framework is further elaborated with the empirical analysis on nuclear power system in order to develop and refine the analytical framework.

In technological innovation literature, it is widely accepted that the systematic management of technological innovation is one of the critical to secure the competitive advantage of the industry concerned and the resultant 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 economy, and to external environment. In this respect, at first the result of this research, namely an analytical framework of entrepreneurial innovation system for nuclear power system, will be very useful to show how all of interactions linked to a nuclear power system could be systematically connected to their ultimate socio-economic value. The analytical framework can also be used for illuminating the causal connections between five core dimensions of the nuclear EIS. Bearing this perspective in mind, this framework of nuclear EIS would be very useful for finding appropriate ways to connect coherently NPS R&Ds and enterprises to NPS industry and in turn national socio-economy which taking into account organization activities performed by entrepreneurs. This nuclear EIS approach could be well used for any countries who want to create new systems or to update their current systems in both developing and advance countries. It will be used for technological innovations for other energy systems. As such nuclear EIS will be very helpful to lead energy technological innovations including nuclear power system with systematic relationships between managerial activities, technological innovation for the industrial competitiveness and socio-economic contributions including its causal linkages with external environments.

The nuclear EIS has to be supplemented and enhanced with further studies particularly in terms of appropriate indicators through the entire life of the system. The performance of the EIS should be operationally measured along with its evolution from creation to diffusion. Operational measures to check the progress of elements in the system are identified to make the framework more practically useful while taking into account specific characteristics of individual technological system and external environments in question. The operational measures should carry their validity and reliability. Validity is concerned with the rationale of the measure which is central in measuring the effectiveness of the measure for the purpose. Reliability represents the quality for the measure to produce the same result repeatedly. The overall EIS through the entire evolution should be explained in particular terms of system boundary and analysis unit. The framework should answer how to explain the difference between the first generation of the EIS, the second and the subsequent ones. Last, the process of interaction between internal elements and the relationship between internal and external elements may vary with the progress of the focal EIS. Therefore critical elements and linkages should be dynamically identified and ranked along the progress through its evolution, which facilitate to design and manage the EIS from a perspective of entrepreneur.

Acknowledgements

A lot of research projects which have been carried out over thirty years in the Korea Atomic Energy Research Institute (KAERI) under the sponsorship of Korean government have been integrated to produce this paper. We appreciate the KAERI and the Korean government for their support. Moreover the earlier

version of this analytical framework was developed in 2014 in working with the Nuclear Knowledge Management Section in the International Atomic Energy Agency (IAEA). However, the authors are solely responsible for all of views and arguments expressed in this article, which should not be ascribed to any organizations including the KAERI, the Korean government and the IAEA.

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