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Smart Grid R&D Planning Based on Patent Analysis

Jason Jihoon Ree and Kwangsoo Kim *

Department of Industrial and Management Engineering, Pohang University of Science and Technology, Pohang 37673, Korea; jjree@postech.ac.kr or jasonree32@gmail.com

* Correspondence: kskim@postech.ac.kr

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Abstract: A smart grid employs information and communications technology to improve the efficiency, reliability, economics, and sustainability of electricity production and distribution. The convergent and complex nature of a smart grid and the multifarious connection between its individual technology components, as well as competition between private companies, which will exert substantial influences on the future smart grid business, make a strategic approach necessary from the beginning of research and development (R&D) planning with collaborations among various research groups and from national, industry, company, and detailed technological levels. However, the strategic, technological, business environmental, and regulatory barriers between various stakeholders with collaborative or sometimes conflictive interests need to be clarified for a breakthrough in the smart grid field. A strategic R&D planning process was developed in this study to accomplish the complicated tasks, which comprises five steps: (i) background research of smart grid industry; (ii) selection of R&D target; (iii) societal, technological, economical, environmental, and political (STEEP) analysis to obtain a macro-level perspective and insight for achieving the selected R&D target; (iv) patent analysis to explore capabilities of the R&D target and to select the entry direction for smart grid industry; and, (v) nine windows and scenario planning analyses to develop a method and process in establishing a future strategic R&D plan. This R&D planning process was further applied to the case of a Korean company holding technological capabilities in the sustainable smart grid domain, as well as in the sustainable electric vehicle charging system, a global consumer market of smart grid. Four plausible scenarios were produced by varying key change agents for the results of this process, such as technology and growth rates, policies and government subsidies, and system standards of the smart grid charging system: Scenario 1, 'The Stabilized Settlement of the Smart Grid Industry'; Scenario 2, 'The Short-lived Blue Ocean of the Smart Grid Industry'; Scenario 3, 'The Questionable Market of the Smart Grid'; and, Scenario 4, 'The Stalemate of the Smart Grid Industry'. The R&D plan suggestions were arranged for each scenario and detailed ways to cope with dissonant situations were also implied for the company. In sum, in this case study, a future strategic R&D plan was suggested in regard to the electric vehicle charging technology business, which includes smart grid communication system, battery charging duration, service infrastructure, public charge station system, platform and module, wireless charging, data management system, and electric system solution. The strategic R&D planning process of this study can be applicable in various technologies and business fields, because of no inherent dependency on particular subject, like electric vehicle charging technology based on smart grid.

Keywords: R&D planning; patent analysis; sustainable smart grid technology; R&D strategy; STEEP analysis; scenario planning; electric vehicle charging technology

1. Introduction

Smart grid is an electrical grid that uses information and communications technology to gather information regarding the behaviors of suppliers and consumers in an automated fashion to improve the efficiency, reliability, economics, and sustainability of electricity production and distribution [1–12]. Through the construction of smart grid, the bi-directional transfer of electrical information allows for increases in rational energy consumption and provides high quality energy and various supplementary services. Furthermore, new business opportunities for green energy and electric automobiles are expected to be established through the convergence of sustainable green technologies. Accordingly, technologically-developed countries, such as the United States of America (USA), Japan, China, and European countries, have established smart grid agencies to fund research on smart grid [1–4,13–17].

For the purposes of a convergent and complex system, like smart grid, a strategic approach is necessary from the beginning of the research planning phase. Investment and research in various fields are essential due to the smart grid being a large-scale system on the national level. Additionally, collaborations in research are mandatory, because the connection between the different technologies is significantly sizable. While the current linear economy utilizes resources to manufacture products and disposes of them after consumption, the smart grid industry also meticulously aligns to the recent growth in interests of the circular economy framework, which aims to achieve a desired zero-waste society [18] through reusable, restorative and regenerative measures of wastes to retain as much value in producing new and renewed products or services [19–21]. Development in smart grid optimization is imperative due to its potential and innate aptitude to improve both the economic and environmental positions in support of the circular economy concept [22–24]. Furthermore, turbulent competition between numerous companies can exert substantial influences on the future smart grid business. Research and development (R&D) planning for smart grid must be established in detail and ensued from national, industry, and company levels due to such diverse reasons.

Currently, strategic planning and research investments are being conducted in regard to smart grid R&D on a national level [1–4,13–17]. However, such strategic R&D planning exclusively depends on groups of experts from various technology disciplines pertaining to the smart grid. Through heavy reliance on expert opinions, a problem arises, as the research plan can be susceptible to skewed biases [25,26]. For example, smart grid government funding can be misallocated toward certain technologies in favor of the interests of these experts for personal or political benefits, rather than for the purposes of advancements of a smart grid. Thus, a systematic and methodological approach is vital to support expert opinions and further increase the legitimacy of the R&D planning process. Through systematic R&D planning, rapid changes in technology, society, and environment can be coped with, both dexterously and continuously.

In this study, a R&D planning process was developed based on patent analysis combined with scenario planning analyses and nine windows from the Theory of Inventive Problem Solving (Russian acronym: TRIZ) [27] in order to construct decisive and strategic suggestions for the competitiveness of the smart grid R&D business. With the developed process, strategic R&D planning was performed on a smart grid company in conjunction to electric vehicle charging technology as a case study. Furthermore, this study has offered a proposition that can cover: (i) short-term strategies utilizing current technologies or technological shortcomings and (ii) intermediate-term and long-term strategies employing future prediction for new business opportunities. The resulting strategies of this study also stretch beyond the classical reliance on the perspectives of experts by using a methodology-based approach, which can provide new, useful, and generally overlooked insights and advices. In addition, the R&D planning process that is proposed in this study is not strictly tailored only for the purposes of smart grid, and it thus may be malleable and suitable for usages in other business R&D planning and strategizing activities for company R&D managers, technology policy and decision makers, and innovative individuals.

The rest of this paper consists of the sections, as follows: Section 2 describes research background, Section 3 depicts strategic R&D planning process, Section 4 portrays the application of the proposed method in a case study of Smart Grid R&D Planning for Hyosung Corporation, and Section 5 describes the conclusion.

2. Research Background

2.1. Strategic R&D Planning

In general, one needs to establish strategic R&D planning ahead of discussing its methodology. R&D refers to "creative work that is undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture, and society, and the use of knowledge to devise new applications" [28]. R&D can be frameworked in a systematic manner, as shown in Figure 1. The evolution of R&D can be classified into several generations, as follows. The first generation of R&D comprises of technologies that are developed through the plethora of investments of past research, which originated from the intellectual curiosity of researchers of various disciplines. The R&D driven by marketing for the purposes of marketability categorizes the second generation. As a result, a trend of cooperation between the R&D and marketing departments and the individual projects for new business starts to develop. The third generation is progressed from R&D projects that are instigated via the strategies of enterprise corporation. Currently, the majority of global companies are stressing the importance and practice of the third generation R&D efforts. Since the beginning of the 1990s, in particular, as companies' R&D activities have been combined with the enterprise corporation strategy, establishing the direction of R&D investment according to strategic goals and markets has become more essential. Finally, the fourth generation extends beyond the third generation R&D by forecasting the future and reconfiguring the business strategy, which accentuates and centers around the R&D strategy.

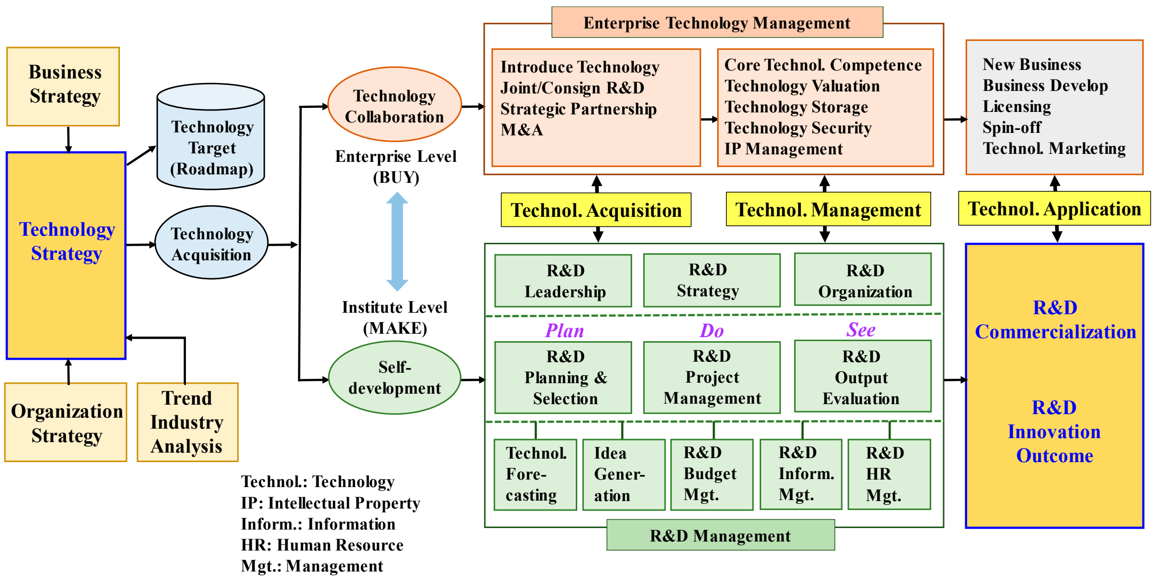

Figure 1. Overview of research and development (R&D) Framework.

2.2. Patent Analysis

Patents are reports of the latest information, which reliably reflects contemporary technological developments and changes. Thus, patent analysis is recognized as an essential process that is required in all assessments of technology trends and technology planning activities [29]. Furthermore, information that was obtained from patent analysis has been utilized in a variety of instances with the advancements of R&D, in particular, for strategic R&D planning.

Strategic R&D planning may be categorized into three stages [30]. As illustrated in Table 1, the first stage of R&D planning is limited to simply patenting the developed technologies without the consideration or application of available patent information. Typically starting from the second stage, patent information is used strategically and, however, the second stage of R&D strategies does not extend beyond an investigation of the prior similar technologies and the defensive strategies regarding patent infringement. Beginning from the third stage of R&D planning, patent information is deemed to be significant and is extensively utilized to its overall potential by comparison to the activities of the first and second stage R&D planning. The patent information is manipulated for various purposes, including merger and acquisition (M&A) technology procurement, new business and product planning, patent valuation, patent licensing, and patent portfolios. Furthermore, the use of patent information for such purposes has become the core trend for the R&D planning activities of technology-based companies.

Table 1. Utilization of patent analysis for each stage of R&D planning.

1st Stage	2nd Stage	3rd Stage
No Strategy Data, Information	Defensive Strategy Information, Knowledge	Offensive Strategy Knowledge, Intelligence

Patent analysis can be divided into qualitative and quantitative patent analyses. Qualitative patent analysis mainly focuses on the technological information of patents in order to discover the core patents and assess technological trends. In addition, patent citation analysis, patent network analysis, and patent map analysis are conducted in qualitative patent analysis to extensively survey not only patents as individual documents, but also as connected entities, for a deeper perception of the technological domain. On the other hand, quantitative patent analysis generally involves the organization and illustration of bibliographical and technological data into graphical format. Through such quantitative analysis, the industry and domain trends of inventors, priority, nation, assignees, and citations can be apprehended.

2.3. TRIZ: The 9 Windows Analysis

Generalizing technologies after the extensive analysis of 40,000 patents developed the Theory of Inventive Problem Solving, or Teoriya Reshniya Izobretatelskikh Zadatch (TRIZ) [27]. Altshuller noted that technology has followed certain patterns and rules in creating new inventive patentable ideas [31]. TRIZ is a useful tool for analyzing technology and countless researchers from various disciplines have applied and validated it. Additionally, TRIZ techniques have been used in the case of technology forecasting and R&D planning activities [32–34].

The problem solving process of TRIZ, as illustrated in Figure 2a, converts a specific problem into one of TRIZ's generic problems, which then is used to apply a generic solution. With a given generic solution, this process is able to find a specific solution to the original specific problem. At a glance, this problem solving process seems to be exceptionally elementary; however, innumerable complex TRIZ tools are being developed to reveal solutions to problems, and substantial research is continuously required to acquire the ability to convert unique problems into TRIZ's general problems. Despite such lingering difficulties, TRIZ remains as a dominant source in coping with problems that involves particular aspects of technology, as well as diverse business problems at a company level.

Other than TRIZ's widely known techniques, such as the 40 Inventive Principles, 76 Standard Solutions and Algorithm for Inventive Problem Solving, or Algoritm Resheniya Izobretatelskikh Zadatch (ARIZ), process, there exists a vast collection of methodologies that have been developed. These methodologies include Technology Evolution Patterns [35–37], Ideal Final Result technique [38], and nine windows technique [39], and more. The 40 Inventive Principles of Problem Solving method solves the technical and physical contradictions [40] and it is "closer to application than the laws of technological systems evolution" [41]. The 76 Standard Solutions help to solve system problems without identifying contradictions and they are applied to alleviate unwanted exchanges between two parts of a system [42], and ARIZ is a logical structure aimed to simplify a complex problem to be easier to solve [43].

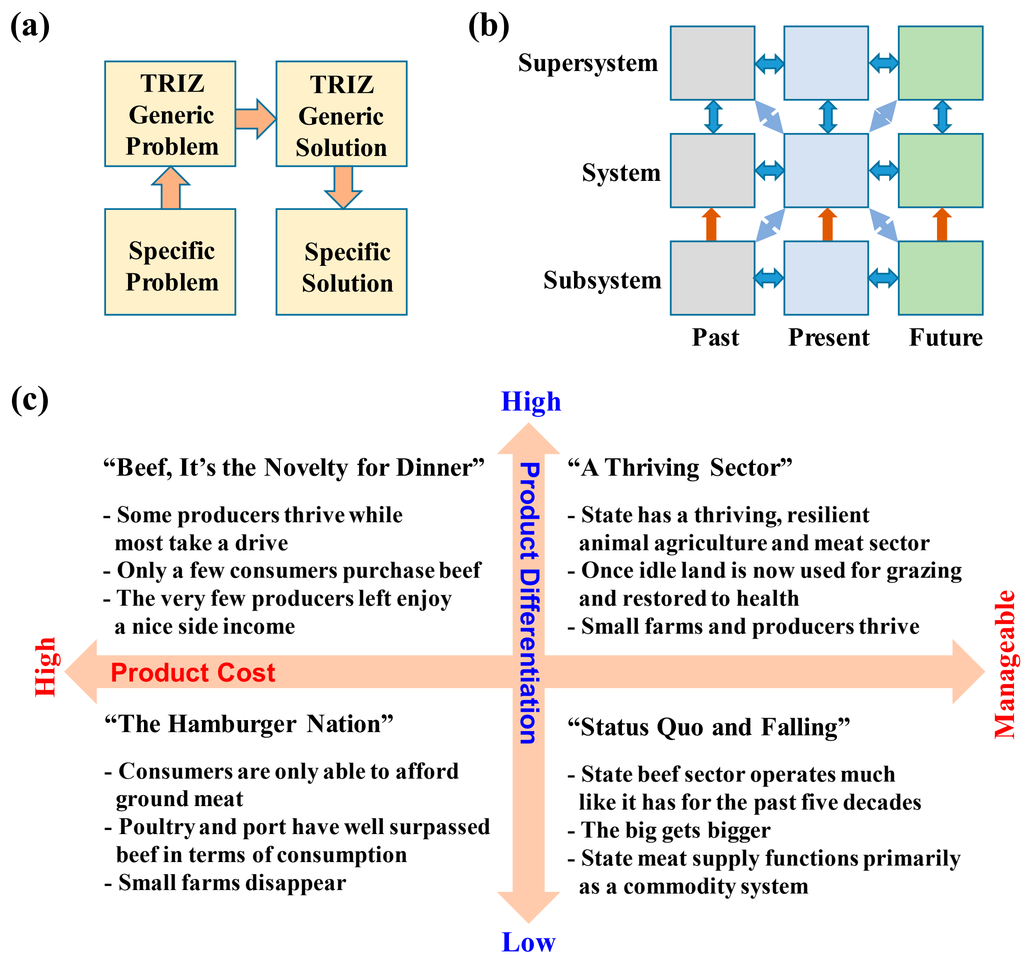

Figure 2. (**a**) Theory of Inventive Problem Solving, or Teoriya Reshniya Izobretatelskikh Zadatch (TRIZ) analysis process; (**b**) Nine Windows analysis; and, (**c**) Example of scenario planning.

While such TRIZ techniques mainly focus on solving technical and physical problems for new product/process development, the nine windows technique was selected and adopted due to its uniqueness in describing how the target domain (system) and its super and sub systems evolve over time to generate a holistic view of the smart grid industry [32]. The nine windows analysis is a multi-dimensional technique that can aid in the prediction of the future by dividing the past, present, and future into sub-system, system, and super-system [39]. By examining the sub-system, system, and super-system of the present and the past of a technology, the corresponding three levels of the future can be more accurately comprehended (Figure 2b). What differentiates this method from other future foresight methods is the relevant utilization of the sub- and super-systems to predict the future in a structural manner.

2.4. Scenario Planning

Scenario planning is a method that is used to deal with uncertainties in the future business environment [44–49]; Figure 2c illustrates a schematic example. The scenario perspective acknowledges the inability to ideally predict the future, and thus prepares for the uncertainties of the future. More specifically, scenario planning primes for the future through the attainment of planned solutions to each feasible and meaningful scenario, which is created with future uncertainty as its foundation. The advantages of scenario planning are as follows:

(i) future business opportunities are investigated via scenarios;
(ii) plans are established by modification according to various different scenarios;

(iii) a clear direction of what capabilities are required in the future is suggested appropriately;
(iv) current established plans can be tested for suitability under future circumstances; and,
(v) crises and emergencies can be dealt with beforehand.

3. Strategic R&D Planning Process

3.1. Smart Grid Strategic R&D Planning Process

In this study, a strategic R&D planning process catered toward smart grid industry has been developed and it is shown in Figure 3.

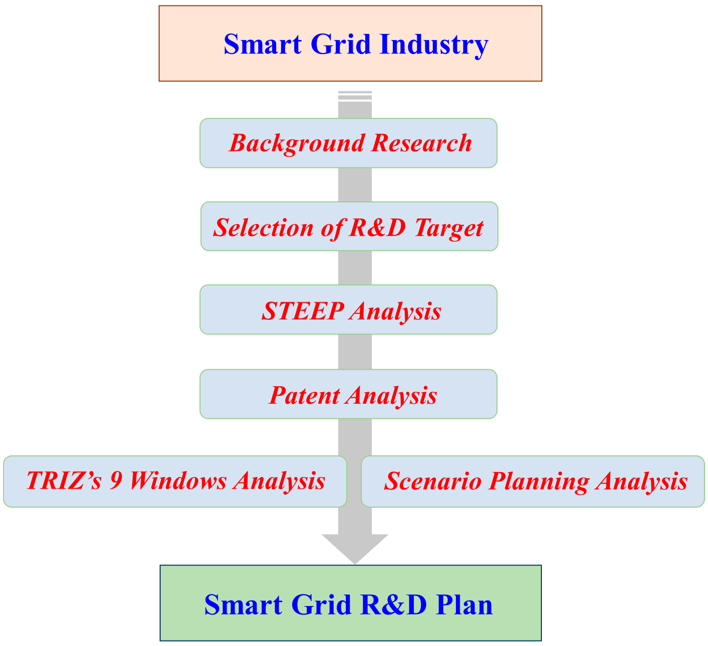

Figure 3. Strategic R&D planning process for Smart Grid.

First, thorough background research was performed to establish a strong foundation regarding the smart grid industry. To achieve this, interviews with domain experts and policy makers were conducted in parallel to obtain a concrete understanding of research trends in smart grid, in addition to surveying smart grid related text books, reports, magazines, academic literatures, and internet documents. Furthermore, the perspective target of research has been selected. The selection of such a perspective target of research is essential, because the methods and details of the analysis are distinguishable, depending on whether the perspective target is a company, industry, or nation. This study pinpoints a company as the target and its association with the smart grid industry. Since the smart grid industry is quite vast with an eclectic array of different technologies and domains, this study further focuses on one of these for an in-depth analysis, rather than a superficial overview of the entire industry containing little significance and credibility. This study also utilizes the societal, technological, economical, environmental, and political (STEEP) analysis for the development probability of smart grid industry, because the analysis is a suitable methodology that yields macro-level insights that are useful for the direction in the beginning phase of research planning. The STEEP analysis pinpoints key elements that induce significant influences on the smart grid industry (Table 2) [48].

Table 2. Societal, technological, economical, environmental, and political (STEEP) analysis results of smart grid industry.

STEEP	Smart Grid Drivers
Environmental	• Reduce green-house gas emissions • Support and lower cost of Kyoto Compliance • Increase renewable energy generation • Improve energy efficiency
Regulatory/Governmental	• Respond to governmental mandates (i.e., UK, Netherlands, Sweden, US, Australia, Brazil, etc.) • Support building renewable/distributed generation • Support performance-based rate making • Enable national security objectives • Facilitate wholesale and retail market efficiency
Economic	• Improve reliability (e.g., decreased outage duration and frequency, etc.) • Reduce labor costs (e.g., meter reading and field maintenance, etc.) • Reduce system losses (e.g., better systems planning and asset management, etc.) • Reduce non-labor costs (e.g., field vehicle, insurance and damage, etc.) • Provide revenue protection (e.g., better billing accuracy, prevention/detection of theft/fraud, etc.) • Provide new revenue sources (e.g., energy management, etc.) • Deferral of large capital projects (e.g., reduced generation requirements, etc.)
Societal	• Respond to consumer demand for sustainability and enhanced ability to manage their usage • Respond to customers increasing demand for uninterruptible power • Provide customer options for energy conservation
Technology & Infrastructure	• Invest significant capital for development of new technology (improvement of existing technologies) • Replace outdated T&D infrastructure • Decreasing workforce (e.g., 50% of technical workforce are expected to reach retirement age in 5–10 years)

T&D: transmission and distribution.

Subsequently, starting with the target company's patents performs patent analysis; them, the company's capabilities can be examined. In this case, the company's capabilities are evaluated in regard to the smart grid industry by exploring the company's patents, past developments and businesses, and changes in focus of areas and investments. With the company's capability information, patent analysis is conducted again to shed light upon the specific areas in which the company can expect business opportunities. Through the analysis of the specific areas within the smart grid industry, robust knowledge can be obtained to further investigate industry growth, development trends, core technologies and technology trends, and the insight of market competitors, thus offering a foundation for strategic R&D planning activities.

Finally, extending beyond the analyses of the target technology, future strategies can be established by using TRIZ's nine windows and scenario planning methodologies. Through the nine windows methodology, the smart grid's current system and super-system can be analyzed to chronologically draw a conclusion and prediction of the future's super-system and system. In detail, the current system's shortcomings (problems) are identified. After an evaluation of the specific problems at the current system level, the problems of the current super-system are established. The most probable solutions or portrayal of the future in accordance to the current super-system is formulated in the future super-system. Finally, under the assumptions that the future super-system holds true, specific future solutions at the system level are created. For example, while assuming that the current problem (current system) is the subpar or lack of internet access on commercial airplanes, the current super-system problem is the lack of long-range tower or satellite infrastructure and the reliability of signal receiving antenna technology. The future super-system solution may become the advancement and dominance of satellite-provided internet connection. Assuming this development in satellite-provided internet, the R&D plan would consequently suggest developing antennas that are specialized for satellite connectivity as the solution.

The scenario planning is composed of six step processes, as follows. (i) Selection of core issues: Regarding what affairs, will decisions be made? (ii) Extraction of decision-making factors: What is required to be able to make decisions? (iii) Investigation of the motive for change: What is the significant cause for change? (iv) Abstraction of the scenario: What/which scenario is significant? (v) Dictation of the scenario: How will the future unfold? (vi) Establishment of counterstrategy: How will the future be coped with? The resulting future system is utilized for R&D planning. In addition, the uncertainties of future can be dealt with the scenario planning methodology through the creation of multiple scenarios that are based on key change agents. A robust smart grid strategy can be established as a result of these processes.

3.2. The Smart Grid Industry

The future of the energy industry is rapidly expanding towards an efficient and reliable smart grid infrastructure. The smart grid industry and technologies can provide a variety of benefits, not only for developed countries, but also for developing countries. The smart grid can: (i) increase the energy efficiency; (ii) decrease the losses from the electrical grid; (iii) improve system performance and asset utilization; (iv) combine the sources of renewable energy; and, (v) actively cope with energy demands. Particularly, since the 2000s, the implementation of smart grid has received much attention [1–4], especially after immense capital losses that result from frequent major blackouts and their consequent damages [6]. From the development of local microgrids [6,10,50] to country-level case studies and R&D funding initiatives [13,17], significant strides toward smart grid planning and development have undergone thorough discussion, evaluation, and support, both nationally and internationally [14,15,51,52]. Furthermore, in support of the growing interests in the circular economy concept, the smart grid possesses prodigious capacity to accommodate efficient, renewable, and reusable energy solutions to many aspects of the energy grid, e.g., power generation, distribution, and consumption [22]. Many research endeavors have been performed to address the capabilities and opportunities of smart grid in respect to the circular economy framework [18], most notably to address the roles of digital and smart technologies [20,23] and the monitoring of energy generation [51], transmission, distribution [52], consumption [53], and management [50–54] in smart grid scenarios [24].

The smart grid can be seen as a complete package that contains electricity generation, transmission, distribution, and consumption [55], as illustrated in Figure 4. When the infrastructure for the smart grid is constructed, the current electrical grid changes from a class-like composition with distinct roles (generation, transmission, distribution, and consumption) into a network structure where multiple entities can simultaneously act as the consumer and the supplier. While the current electrical grid is the infrastructure solely existing to supply electricity, the smart grid can be perceived as an evolved version of the electrical grid, in which home appliances, telecommunications, automobiles, constructions, and energy are intertwined as a platform. The smart grid can allow a new era of innovative and pristine businesses and technologies to propagate, such as bidirectional communication between the electric supplier and consumer, real-time payment systems, reactive response to demand fluctuations, and electric automobiles. Additionally, the smart grid has great potential to act as a strong foundation for new developments that are aimed at renewable energy solutions alongside its native ability to efficiently manage energy distribution and consumption, which is in line with the circular economy concept.

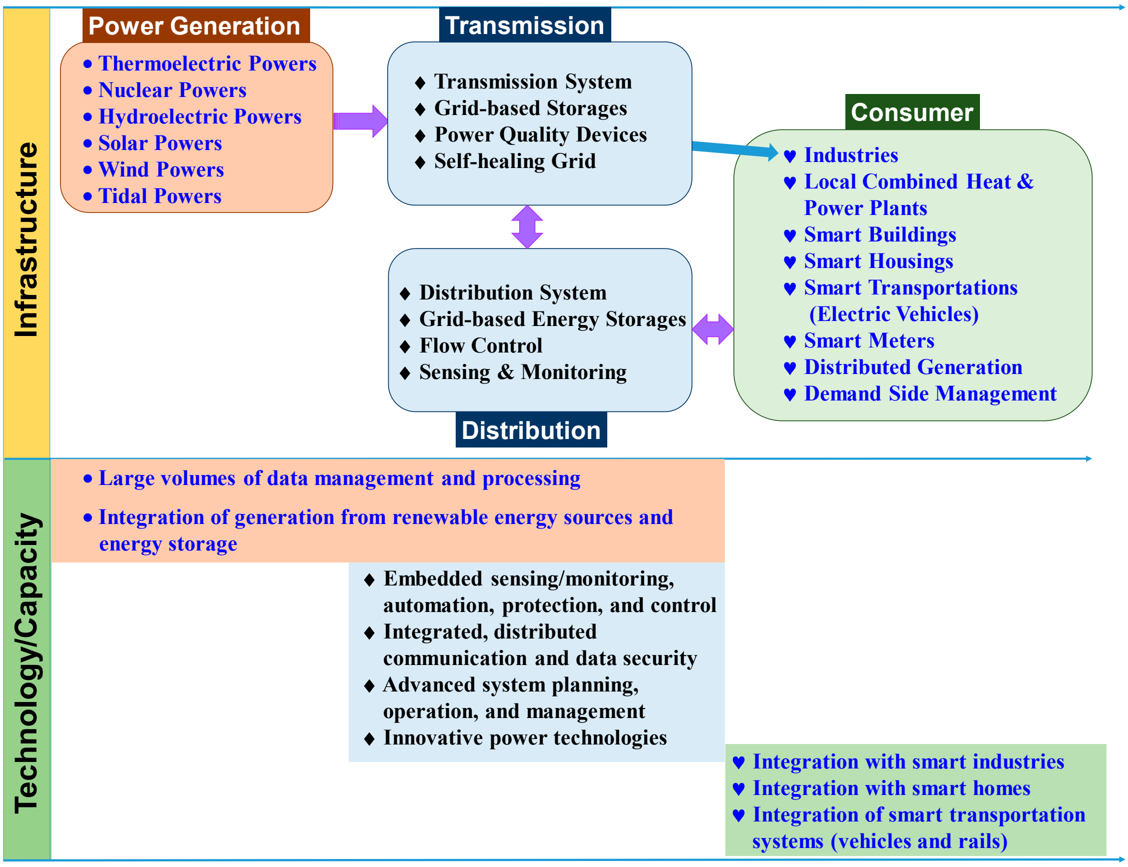

Figure 4. Conceptualization of Smart grid features.

In this study, the fourth generation R&D phase was considered, as described in Section 2.1, from the current third generation R&D processes in regard to smart grid industry. The R&D planning phase was focused on predicting future technologies, create ideas, and extract company strategies based on R&D strategies. In general, prior to strategic R&D planning, efforts have relied heavily on groups of experts from various domains. Although human efforts are ultimately needed to predict the future, establish plans, and make decisions, the significance and demand for a systematic and methodological approach to cope with today's large upsurges of information and the rapid and drastic changes in society is growing.

The smart grid industry may comprise of five industry sectors [56]; Table 3 lists their core technologies and demands. First, the smart power grid sector can be perceived as the industry that increases the reliability and management efficiency of electrical grid by integrating information and telecommunications. The smart power grid technology can be further subcategorized into smart transmission system, smart distribution system, smart power device, and smart power communication network technologies. Second, the smart consumer sector focuses on increasing energy efficiency through communications infrastructure that provides consumers with an assortment of different services. The smart consumer sector consists of automated meter infrastructure, energy management system, and bidirectional communications network technologies. Third, the smart transportation sector concentrates on the generation of new business opportunities through the unrestricted two-way connectivity of electrical grid to electric vehicles. Furthermore, this technology aids in reducing emissions of greenhouse gases, such as carbon dioxide, hydrocarbons, nitrogen monoxide, and sulfur oxide, and in increasing the efficiency of grid through its sub-sectors, such as electric vehicle parts and materials, charging infrastructure, and vehicle-to-grid technologies. Fourth, the smart renewable sector allows for the renewable energy sources to successfully and stably link with the current electric grid by managing the obstacles that hinder the supply of renewable energy. This area comprises of technologies of micro-grid, energy storage, power quality, and power exchange infrastructure. Finally, the smart electricity sector aims to increase the electric grid's efficiency through developing various electric billing schemes and consumer electric transactions system, as well as a reactive response to demand and unrestricted electricity trade between all stakeholders. This sector consists of smart real time pricing, smart demand response, and smart power exchange technologies.

Table 3. Smart grid industry sectors and core technologies.

Smart Grid Industry Sector	Core Technology
Smart Power Grid	(1) Smart transmission system: SMES, FACTS, HVDC, WAMS, WACS (2) Smart distribution system: Distributed generation, AMI, Smart switch, PCS, Converter (3) Smart power device (4) Smart power communication network
Smart Consumer	(1) Duplex transmission AMI, In home device (2) Energy management system (3) Bidirectional transmission network
Smart Transportation	(1) Electric vehicle component & material (2) Electric vehicle charging infrastructure (3) Vehicle to grid
Smart Renewable	(1) Micro-grid (2) Energy storage system (3) Power quality, Power exchange infrastructure
Smart Electricity	(1) Real time pricing (2) Demand & Response (3) Power exchange

SMES: super-conducting magnetic energy storage; FACTS: flexible AC transmission system; HVDC: high voltage direct current; WAMS: wide area monitoring systems; WACS: wide area control systems; AMI: automated metering infrastructure; PCS: power conversion system.

4. Case Study: Hyosung's Smart Grid R&D Planning

Hyosung Corporation is a Korean industrial conglomerate that was founded in 1957. It operates in various fields, including power systems, industrial machineries, chemicals, information technology, constructions, and trades. Among Hyosung's eclectic specialties, this case study has aimed to focus on strategic R&D planning to enhance the competitiveness of the smart grid business sector within the Hyosung Corporation.

4.1. Patent Analysis

4.1.1. Patent Analysis: Hyosung Corporation

In this case study, the patents that Hyosung Corporation currently possessed since its establishment were searched and analyzed; the total number of patents that are owned by Hyosung amounts to 4398 patents. The majority of these patents were registered in the period of 1998 to 2018; only 371 patents were filed for the first forty years (1957−1997) since Hyosung was founded. As shown in Figure 5a, the number of patents increased to a maximum 126 in 1998, corresponding to 34% of the total number of the patents disclosed for the first forty years. However, it turns to be reduced to 116 in 1999 and reached a minimum 47 in 2000. The number of patents slowly increased again to 69 in 2001, 63 in 2002, 98 in 2003, and 139 in 2004. Here, it is noted that the lowest numbers of patents in the period of 2000 to 2002 might be attributed to the severe economic crisis of Korea that started at the end of 1997. The number of patents drastically increased to 324 in 2005 and it reached a maximum 358 in 2006. Again, in the last quarter of 2008, the global recession is speculated to have caused the rapid decline in registered patents since its maximum in 2006. Thereafter, the number of patents annually fluctuates in an upward trend. Overall, these patent data reveal a trend that Hyosung has maintained continuous R&D growth, despite the Korean economic crisis and global recession.

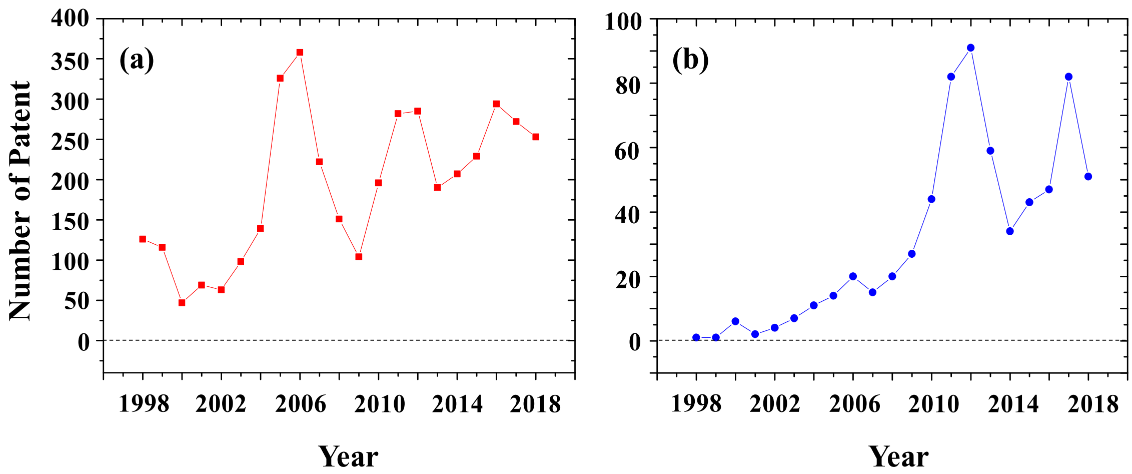

Figure 5. Hyosung's annual number of patents disclosed in the period of 1998 to 2018: (**a**) all possessed technologies (total 4027 patents); (**b**) technologies disclosed to smart grid: electric power components and systems, solar energy components and systems, wind energy components and systems, and battery components and systems (total 661 patents).

The analysis of all Hyosung patents exhibits an active surge in patent registrations across all areas. The corporation has possessed patents in diverse areas that are mainly converged around polymers and downstream products (fibers, tire cords, films, sheet, blends, and composites), chemicals, banking machines, electric power components and systems, solar energy components and systems, wind energy components and systems, and battery components and systems. Overall, the patent analysis confirmed that the company has engaged and invested in robust R&D activities since around 2003.

This study has further narrowed the scope of analysis by concentrating on patents pertaining to specific areas, such as electric power components and systems, solar energy components and systems, wind energy components and systems, and battery components and systems, which have direct associations with the smart grid. As a result, 661 patents were selected for further analysis. It is observed that the patents and technologies that are related to the smart grid begin to proliferate starting 2003 and continue to increase overall (Figure 5b). It can be noted that the decline of patents related to smart grid in 2014 may be a repercussion of the 2008 global recession. A recession can directly impact R&D related expenditures in the form of employee layoffs, project terminations, and budget cuts in forthcoming R&D proposals. Additionally, accounting for the time required for R&D to yield patentable results and the one- to two-year duration that is required for patent registration, the aftershock of the 2008 recession seems most evident in explaining the decrease in numbers of patents that were registered in 2014. The increase in patent numbers after 2014 may be an indication of recovery from the recession.

The technologies of Hyosung Corporation that were disclosed to smart grid in the period of 1998–2018 could be categorized into transformers, switchgears, electronic devices, electronic systems, wind turbine systems, solar systems, battery systems, and other related components, as illustrated in Table 4 and Figure 6. For key technologies, such as (a) transformers, (b) switchgears, (c) electronic devices, and (d) electronic systems, the numbers of patents start to increase from 2007 and steadily continued growth up to today (Figure 6a–d). Differently, the development of wind turbine systems has been intensively carried out only for the period of 2006−2014 (Figure 6e). A similar trend of patent filings is discernible for solar cells and systems, as well as for batteries and their systems (Figure 6f–g). It is noteworthy that a sharp increase of patents has been registered on the solar cells and their systems in the period of 2009−2013. The registration of patents on batteries and systems has been conducted in 2006 to 2014. While taking into consideration of the buffer time to prepare patent submissions, the concentration of research activities in these key smart grid technology areas began in around 2003 (namely, a few years after the Korean economic crisis), which coincides with when Hyosung started to translate their R&D outcomes into intellectual properties. Overall, the patent data is testimony that Hyosung has devoted significant amounts of investments and research on key smart grid technology areas. As a result, Hyosung has achieved substantial technological competitiveness within the smart grid domain.

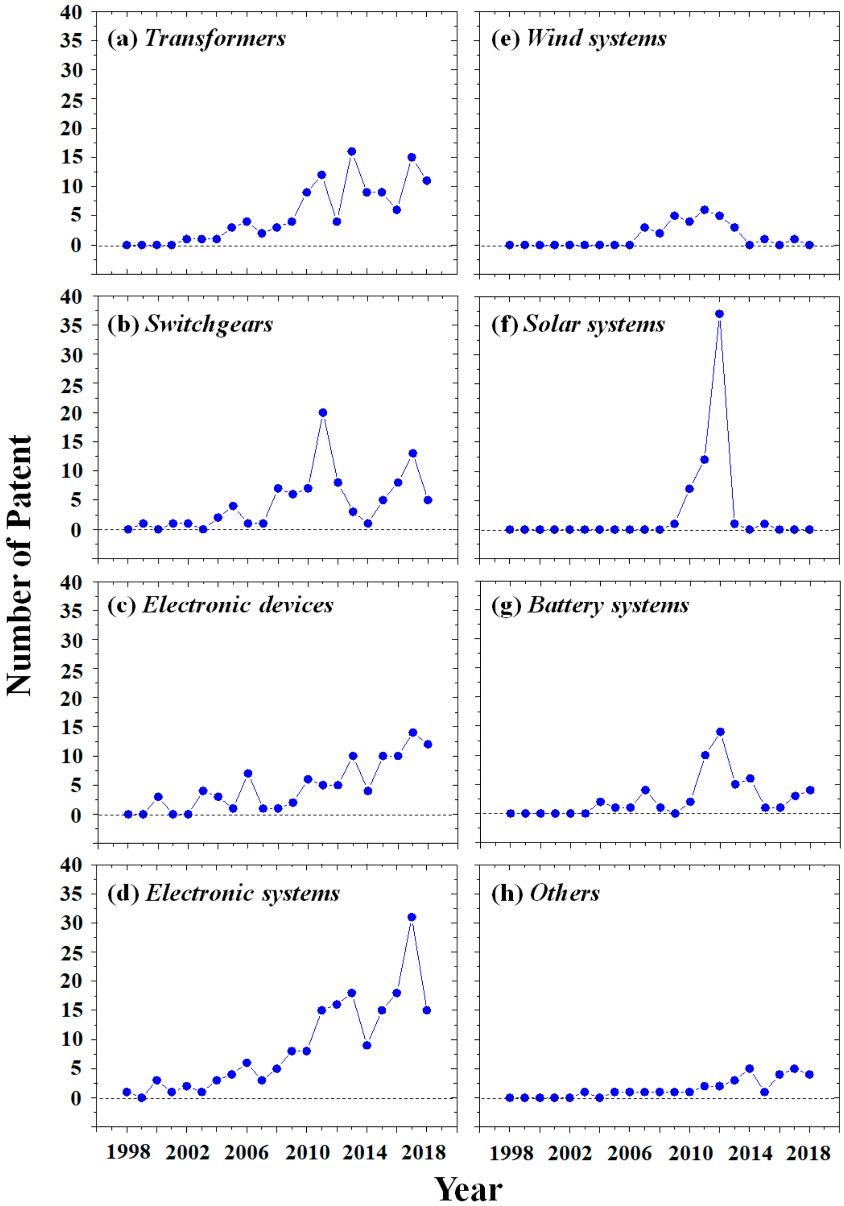

Figure 6. Hyosung's annual number of the patents registered for smart grid technology components: (**a**) Transformers; (**b**) Switchgears; (**c**) Electronic devices; (**d**) Electronic systems; (**e**) Wind systems; (**f**) Solar systems; (**g**) Battery systems; and, (**h**) Others.

Table 4. Smart grid technologies and relevant patents of Hyosung Corporation.

Smart Grid Technology	Number of Patent	Detail Technology
Transformers	110	Power transformer, Oil filled transformer, Converter
Switchgears	94	Gas insulated switch, Disconnecting switch
Electronic Devices	98	Digital protection relay, Detector
Electronic Systems	182	Generator, Control system, Power system
Wind Turbine Systems	30	Wind generator, Wind power system
Solar Cell & Systems	59	Solar cell, Solar generation system
Battery Systems	55	Fuel cell, Lithium secondary cell, NaS battery
Others	33	Motor, Welding machine

As shown in Figure 7, all of the technologies that are owned and patented by Hyosung are connected to the entirety of smart grid industry. In particular, the possessed technologies have competitiveness in the smart power grid industry, smart transportation industry, and smart renewable industry. Through the utilization of the capabilities of transformers and switchgear technologies as a basis, high potential exists regarding entering the smart transmission system business and smart distribution system business within the smart power grid industry. Additionally, the entry barrier for the electric vehicle components and charging infrastructure businesses of the smart transportation industry is considerably low when situating the capabilities of battery systems, electric motors, and electronic systems as a foundation. Aside from these business entry possibilities, Hyosung's patented technologies can provide a strong base to potentially succeed in entering the core of the future energy industry, the smart renewable energy business, and the smart grid system solution business.

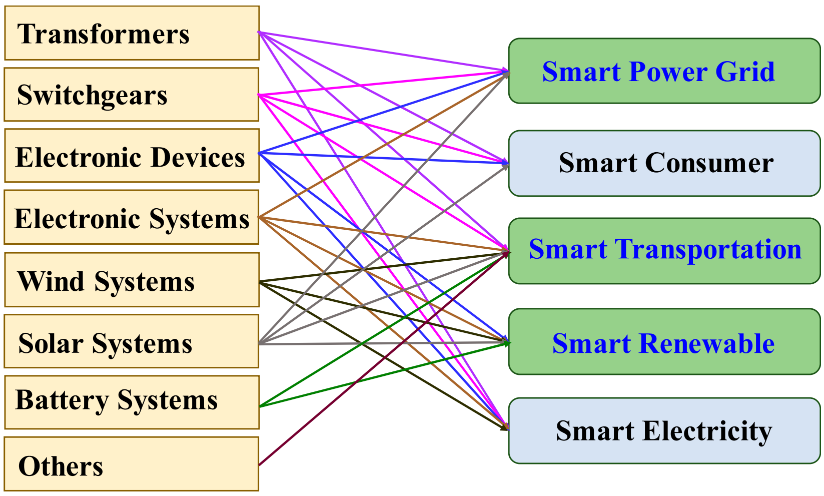

Figure 7. The map of Hyosung's technologies and smart grid industry relations.

4.1.2. Patent Analysis: Electric Vehicle Charging System

This study has selected electric vehicle charging infrastructure business as a focal point for further analysis. The smart grid allows for electric vehicles to be cost-effectively and efficiently charged through selective power usage. For example, electric vehicles can be charged during the night if the price of electricity becomes cheaper as the demand of electricity decreases. Not only does this enable electric vehicle fuel prices to decrease, but this also alleviates the problems that result from the long charging hours that are required for electric vehicle batteries. The remainder of this section analyzes patents regarding electric vehicle charging methods.

The convenient and effective charging of electric vehicles is a world-wide issue. Thus, 15,820 patents that were filed to Korea, USA, Europe, Japan, and China in the period of 2002 to 2018 for electric vehicle charging technology were retrieved (Table 5). Among these patents, 414 patents have been selected for analysis after filtering the noise and directly unrelated patents (Table 5). There is a discernible trend in the patent registration, as shown in Figure 8. The registration of such patents begins in the early 2000s. Only one to four patents are annually registered until 2007. Thereafter, the number of registered patents rapidly increases every year, reaching to a maximum (58 patents) in 2011. It turns to decrease to 44 in 2012 and 40 in 2013, reaching a minimum (28 patents) in 2014. Subsequently, it again turns back to increase to 34 in 2015, 48 in 2016, and 53 in 2017. Nevertheless, in 2018 it again drops to 24.

Table 5. Number of patents disclosed in 2002–2018: Battery charging technology.

Country	Number of Patent	Number of Patent (after filtering noise)
Korea	1407	39
USA	3234	43
Europe	1675	5
Japan	4458	147
China	5046	180

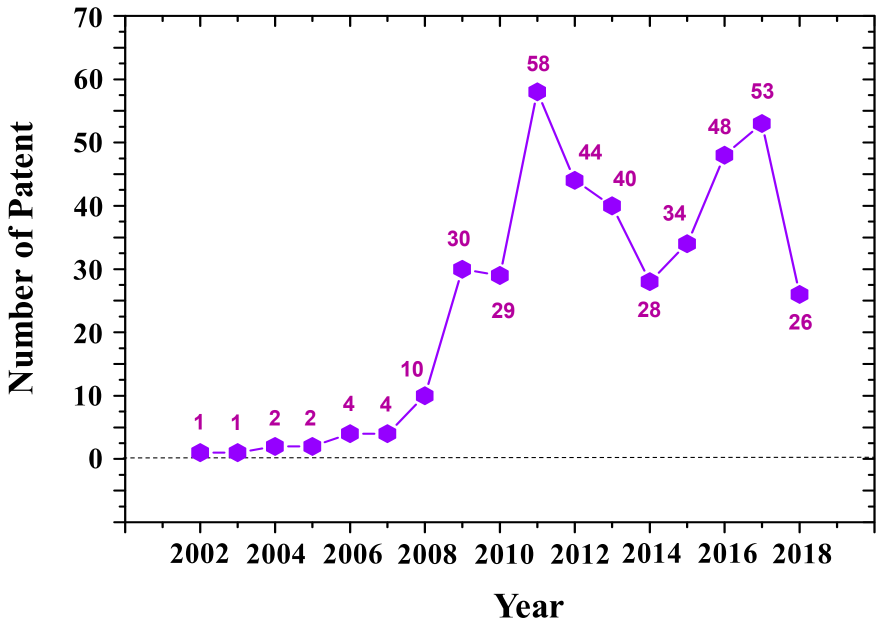

Figure 8. Annual number of patents disclosing battery charging technology.

The patents have been further analyzed in regional bases (Figure 9; Table 5). In Korea, the first patent of electric vehicle charging technology appears in 2004. Subsequently, the patent registration of this technology was actively done between 2009 and 2012, and then declined thereafter. Although similar trends of patent filing are observed in USA and Japan, the overall number of filed patents is slightly higher in USA or much higher in Japan, when compared to that of Korea. However, a slightly different trend of patent filing activity is observed in China. The first patent was filed in 2006 and two additional patents in 2008. Afterwards, the number of patent filing has drastically increased, reaching a maximum (44 patents) in 2017. Even in 2018, the number of patents is 26, which is still very high in comparison to the other countries. In contrast, the activity of patent registration is very slow and furthermore very weak in Europe. Overall, the share fraction of patents is 9.4% for Korea, 10.4% for USA, 1.2% for Europe, 35.5% for Japan, and 43.5% for China. These data confirm that Japan and China dominate the patent registrations, followed by USA, Korea, and Europe. In general, a few years of research are necessary for filing patents. Taking this fact into account, it is evident that, for the recent seventeen years, aggressive research and investments have been devoted worldwide to develop more efficient and more convenient charging technology for electric vehicles.

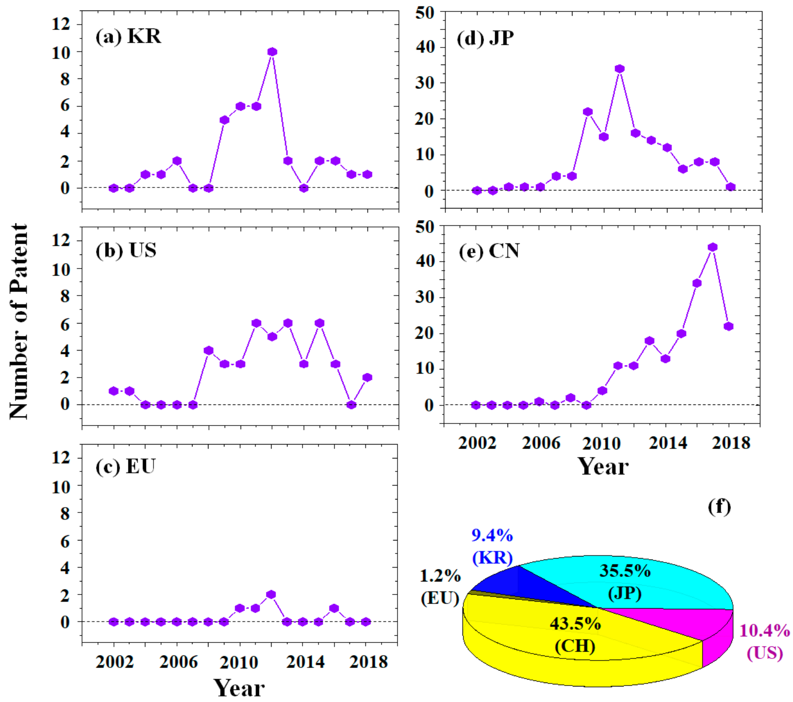

Figure 9. Annual number of regional patents: (**a**) Korea (KR); (**b**) United States of America (U.S.A.) (US); (**c**) Europe (EU); (**d**) Japan (JP); (**e**) China (CH); and, (**f**) Regional patent distributions.

As mentioned above, the R&D of electric vehicle charging technology has been carried out in the fierce competition among the Asian region (Korea, Japan, and China), the American region (USA), and the European region. These competitive R&D works have been found to be led by top 28 organizations, as shown in Figure 10. In particular, the State Grid Corporation of China, Toyota Motor, Kawamura Electric, Hyosung, Mitsubishi, Sharp, LSIS, JFE Engineering, and China Electric Power Research have played dominant leading roles by holding the majority of electric charging technologies. Hyosung and LSIS represent Korea within the top nine applicants. Among the Korean automobile companies, only Hyundai Motor and Kia Motors are barely listed within the top twenty-eight patent applicants. In addition, it is noteworthy that three universities, namely Kookmin University, KAIST (Korea Advanced Institute of Science & Technology), and Tsinghua University, are ranked within the top twenty-eight applicants. Overall, the R&D of electric vehicle charging technology has been driven mainly by automobile, electric power, heavy engineering, and electronic companies. Additionally, there exist instances where academic research groups have worked and filed patents conjointly with such leading companies.

For the electric vehicle technology patents, a thorough and meticulous examination has been performed for each patent to ultimately survey trends in the technology R&D. Furthermore, key development factors have been selected in order to categorize the patent data pool. Subsequently, the core patents of the electric vehicle charging system technology have been chosen. Figure 11 presents the analysis results. In the 2000s, research effort has been focused to develop electric vehicles, batteries, charge methods, charging devices and controls, private power station, and charge infrastructure; these R&D efforts have been continued until recently. In the late 2000s, such developments have begun to emerge in the charging methods and charge control domains. As the developments of individual parts and equipment have matured, the charge service, infrastructure, and system developments have started to emerge from the 2010s to today. Three main key R&D factors have been extracted through the patent analysis of electric vehicle charging technologies. These three factors consist of the electric vehicle battery technologies, the technologies to charge batteries, and the technologies to efficiently manage data via the smart grid. These key R&D factors are organized into specified R&D targets and directions, matched with respective relevant patents, and are summarized in Table 6.

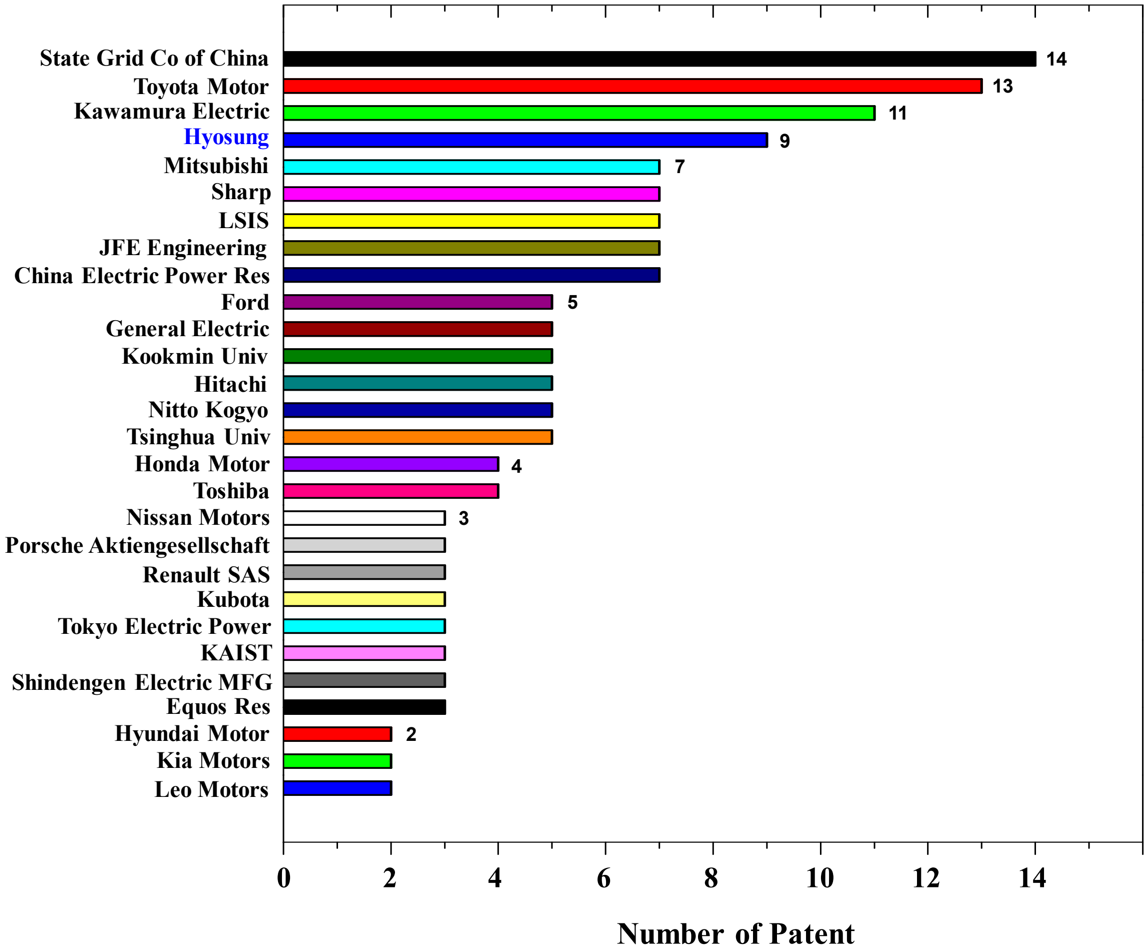

Figure 10. Top patent applicants in the electric vehicle charging technology.

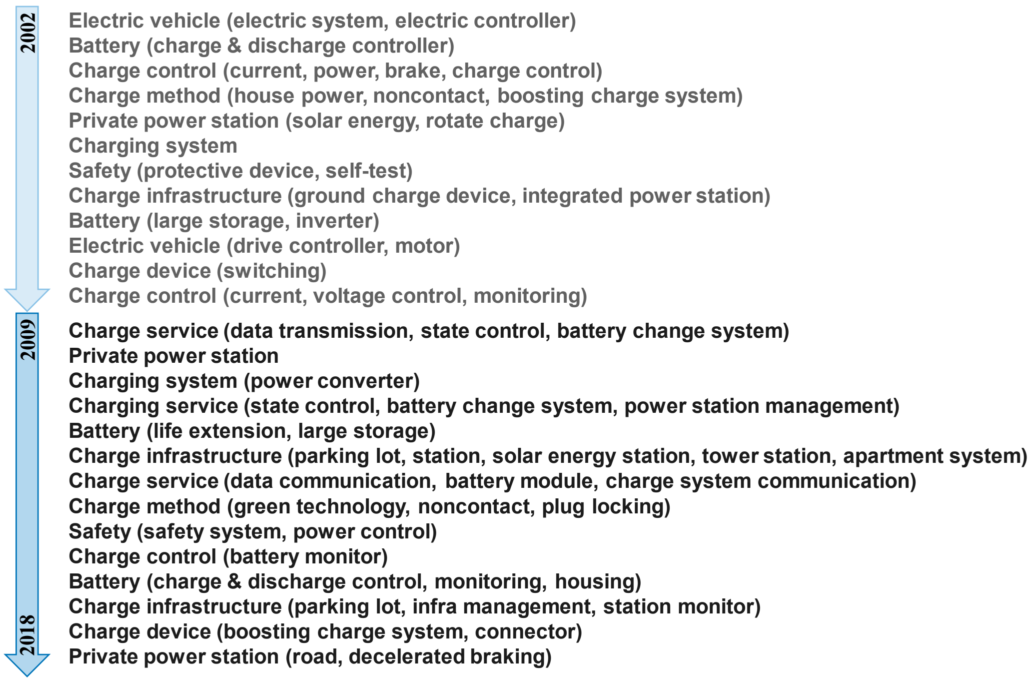

Figure 11. Results of yearly R&D trend analysis in charging technology.

Table 6. Key R&D factors, targets, and directions of electric vehicle charging technology.

Key R&D Factor	R&D Target	R&D Direction	Patents
Data management	*Electric vehicle's effective data management*	Charging system management	US20050199704A1P, US20090021213A1P, US20140266047A1, JP20100146569A2P, KR20100006913A_P, KR20110138564A_P, KR20100059641A_P, CN105098905A, CN102255113A, KR1020130047901A, CN103914749A
		Power data management	US20110251753A1P, US20110010281A1P, CN107462823A, CN103909910B, CN101685890A, JP20100146568A2P, JP20090227189A2P, JP20090089474A2P, JP20080043174A2P, JP20070318849A2P, JP20060117241A2P, KR20070091762A_P, KR20110101846A_P
		Information management	JP20110143923A2P, JP20110103048A2P, JP20110048430A2P, JP20070206889A2P, CN103795093A, CN102315677A, US20120253567A1
Battery	*Improvement of battery performance*	Charge inductor	US00006989653B2P, JP20040364481A2P, KR20100104728A_P
		Power source	US20070200532A1P, US20090212627A1P, US20100001531A1, US00008093861B2P, JP20100268576A2P, EP00001338461A3P, JP20060074870A2P
		Battery charge	US00007208914B2P, US20100114762A1P, US8330411B2, US8334676B2, US8183826B2, CN107650704A, JP20110205758A2P, JP20110151896A2P, JP20100161856A2P, JP20100158134A2P, JP20090100649A2P, JP20090095157A2P, JP20090077557A2P, JP20090060683A2P, JP20090038872A2P, EP00002157637A1P, KR20040108453A_P, JP20090027831A2P, JP20060074868A2P, JP20050210835A2P, CN101527374A, CN106696721A
		Charge device	US20100181126A1, EP00002282390A2P, EP00002279892A2P, EP00002226216A1P, CN108859816A
Charge method	*Effective various charge method*	On-line charge method	KR20050106313A_P, KR20070118872A_P, KR20100002934U_U, KR20110042403A_P, US00007501789B2P, US20110187321A1P, EP00002325037A1P, EP00002292877A1P, JP20100068632A2P, US20120268245A1, US20140266047A1, CN107839502A, CN107128192A
		Public place station	JP20100101082A2P, JP20100095848A2P, KR20100023908A_P, KR20110112656A_P, KR20120009923A_P, JP20120016179A2P, JP20110169043A2P, JP20110018336A2P, JP20100146564A2P, US20120229085A1, KR101245572B1, CN108859843A, CN1074591853A
		Effective charge system	KR20110047950A_P, KR20110048444A_P, US20070188126A1P, EP00001961098A2P, US20120313562A1, CN103311978A, US9517700B2, US9233618B2, KR1020180084656A
		Auto charge system	KR20050017335A_P, KR20050064899A_P, US00007479763B2P, CN103001264A, CN108407626A

4.1.3. Strategy Based on Patent Analysis

This section is dedicated towards suggesting an entry strategy that is based on R&D targets in regard to the electric vehicle charging system by examining Hyosung's smart grid capabilities. In comparison with the other areas of Hyosung, little research has been conducted in this field. Nevertheless, Hyosung has established a better position in the R&D of battery systems and charging systems, when compared to all other competitors in the world, as discussed in the earlier section. Moreover, recent increases in patents reflect the escalation of its research. When considering that the effective data management field is still an unexplored area in the world market, the battery system and charging system area is expected to be a promising opportunity, under the assumption that Hyosung concentrates its capabilities from its power management system into information and communications technology, and continues R&D efforts in this area.

The battery performance and charging technology, among all electric vehicle related areas, has been the most actively researched area. Notably, Japanese companies currently possess the technologies of the highest standards, as well as the bulk of the core technologies. Nevertheless, research of battery performance will proceed to the continual advancements in performance of electric vehicles. Although the Japanese competitors possess many of the core technologies regarding the performance of electric vehicle battery technologies, the opportunities exist, given that Hyosung allocates its capabilities of power equipment and battery technology to conduct research in reducing battery charging durations.

Various charging methods are closely related technologically and, more importantly, highly interconnected to the electric vehicle charging industry's business model. Though several business models have been developed, there has yet to be a model that can be recognized as a world-wide standard. This area is not limited to the development of charging technologies, but it must incorporate the developments of an all-inclusive mixture of the power equipment system, service, and infrastructure.

4.2. Future Strategy

This research goes beyond technological analysis by establishing a strategy from a business perspective. TRIZ's nine windows and scenario planning methodologies have been utilized to provide a strategy from a business point of view.

4.2.1. The 9 Windows Analysis

In order to stimulate the market of electric vehicles, a consumer-friendly and convenient, not to mention efficient, electric vehicle charging system is a vital element. The electric vehicle charging system must be able to use cost-reduced power during the night and to minimize the problems faced during demand data management and demand fluctuations to properly coincide with the goals of the smart grid industry. The electric vehicle charging system has been analyzed at the current system and super-system levels in a consecutive manner to achieve these. Figure 12 shows the analysis results. The current problem at the system level pertains to the problems with performance, implementation, and expansion of private charging stations. A 24 kWh Nissan Leaf charged into a normal Level 1 (1.4 kW) residential outlet for roughly twelve hours only recharges the battery to half capacity and would cost approximately $60 per month; and, it costs $1500–$2200 for users to install a Level 2 220-volt (6.6 kW) system, which is capable of fully charging the car in seven hours [45]. Essentially, long charging time, the cost of electricity, and private charging unit installation are some of the major issues in electric vehicle charging. For the super-system, system standardization is considered to be a generalized problem of the system due to the lack of a global standard in place for electric vehicle charging, which consequently affects the expansion of charging infrastructure, a vital element that is required for electric vehicle adoption [57]. For the future super-system, the current issues of industry standardization are resolved and the vitalization of smart grid technologies and its benefits have instated. In correspondence to this super-system, the future system of electric vehicle charging is expected to promise the expansion of highly available, affordable, and rapid charging stations, where the company can position its R&D planning activities.

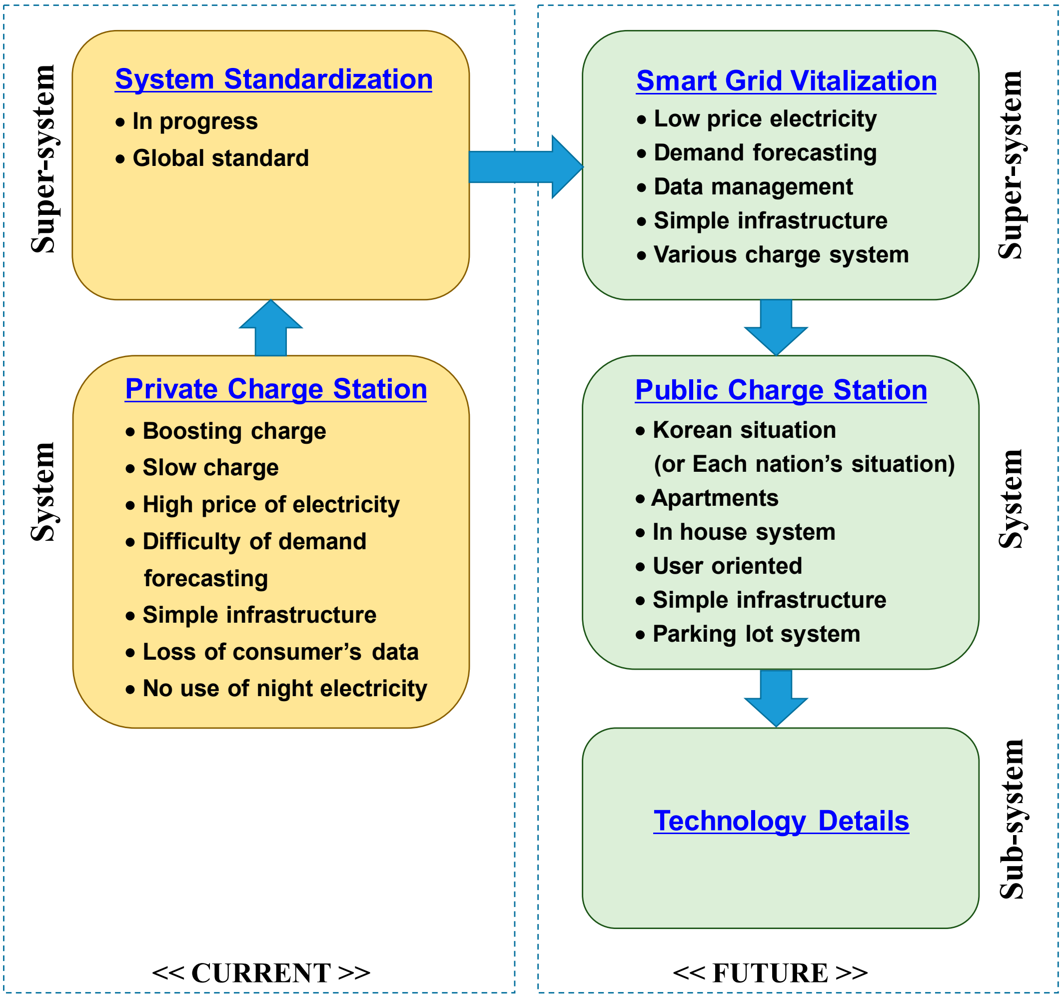

Figure 12. Results of the nine windows analysis for smart grid industry in conjuction to electric vehicle charging technology.

The contemporary plan and development of electric vehicle charging system is close to that of the current gasoline station. Although research is attempting to solve the biggest issue of the charging system, namely extensive charging durations, twenty-minute boosted charging, and five-hour slow charging stations are being implemented at present. The implementation of ultra-fast charging stations is being contemplated, but the expensive costs are acting as an unavoidable obstacle. In addition, private charging stations incur limitations, since user data management is difficult to the point where demand prediction is overly complex to satisfy the efficiency standards for the smart grid.

In its current state, it is a world-wide plan to set a universal standard for the smart grid charging system. Domestically, basic systems requirements and safety regulation standards have been arranged; and similarly, the US, Europe, and Japan have proceeded to create their own national standards. Preparation in advance is essential, because the universal standardization of the smart grid charging system will set the world-wide norm.

The progress toward the smart grid is becoming factual in the future super-system. When the smart grid becomes activated, the smart grid's advantages must be sufficiently utilized. For example, the cost-reduced power during the night is selectively used by the consumer, and, through data management, the predictions of demand and supply are accurately accomplished. Furthermore, a surplus of different charging systems will be provided to fit and satisfy individual lifestyles and preferences.

Predicting the future system based from what was foreseen in the future super-system, the charging system infrastructure must be customized to fit into all types of housing environments. For example, the charging systems are implemented within the apartment housing parking facilities for each parking spot, and to implement water-proof enclosures for outdoor charging units for other types of parking. Moreover, payment system and data management system developments are required in maintaining the charging infrastructure. The scenario planning technique is utilized to fine tune the directions of the R&D plan with the resulting future system and super-system as a reference to guide the types of electric vehicle charging innovations.

4.2.2. Scenario Planning

This research uses scenario planning to establish strategies for countering the extracted plausible future scenarios. Key change agents, namely technology and growth rates, policies and government subsidies, and system standards of the smart grid charging system, were generated and combined accordingly to produce the following four most plausible scenarios (Table 7).

Table 7. Future smart grid industry scenarios.

Scenario	Technology Rate	Growth Rate	Regulation	Standardization
1	Fast	Fast	Low (support)	Uniformity
2	Fast	Fast	Low	Diversity
3	Fast	Slow	High	Uniformity
4	Slow	Slow	Low	Diversity

In Scenario 1 (The Stabilized Settlement of the Smart Grid Industry), the future setting can be hypothesized as the following. The advancement of the technology is sufficient; the growth rate of the smart grid and electric vehicle charging system industry is accelerated; government subsidies are strongly supportive; and, the industry standard is strictly uniform. In this scenario, related markets are growing, and innumerable companies are heavily investing in R&D in the hopes of entering the smart grid industry. Although this is a prime instance for successful opportunities, the strictly uniform standardization policy plays a significant role in determining the outcomes of such opportunities. It is vital to recognize and closely monitor the standardization policies as the key change agent from a company's perspective. Regardless of the supremacy and excellence of a technology, if the technology strays from the standardization guidelines, then the risk of failure is inevitable.

In order to prepare for Scenario 1, the company must avoid investing in a new all-inclusive charging system, and focus R&D expenditures on the development of various modules or a platform that concurs with the current and predicted standards. It is suggested to capture the business opportunities in developing individual modules and related technologies that lie within the boundaries of the standards, since the future charging system will diversify into varied businesses.

Scenario 2 (The Short-lived Blue Ocean of the Smart Grid Industry) can be described as the environment, where adequate advancements of technology, rapid growth rates, hefty government aid, and the freedom from standardization are harmonized. It may seem that all of the stars have aligned in this scenario, where all of the external factors are in favor for opportunity. However, in this scenario, the lack of regulation of any form results in a highly competitive atmosphere and causes rapid and impulsive advancements of the technology.

As a result, an aggressive plan is required to cope with such competition. This plan must encompass continuous R&D activities in a portfolio of different technologies. Not only is it essential to invest in incremental improvements of existing technologies, but it is more important to prepare and further invest into the future to maintain competitive advantages. For example, while developing technologies that enhance the performance of existing charging systems, investments into disruptive innovative technologies are crucial. It is speculated that the future representative technology may become wireless charging technology and robotic charging [58]. The patent analysis results show that wireless charging related technologies have developed starting the late 2000s, though the wireless technology is still in its early stages and far from commercialization for smart grid applications. However, similar to how the wireless charging technology is becoming commercialized for small applications, like cellular phones, the wireless charging technology has great potential to solve certain problems of the electric vehicle charging system. In short, Scenario 2 illuminates a future filled with prosperity and success, but the need for concentrated R&D efforts in disruptive innovations is a difficulty that cannot be disregarded.

In Scenario 3 (The Questionable Market of the Smart Grid), the future can be represented as a situation where ample developments of technology exist and continue to be improved, but the smart grid market is showing slow growth; in addition, governmental grants are low and the standardization is strict. Thus, the situation, where companies have heavily invested in the smart grid industry, but are struggling in difficult times due to a combination of factors mentioned, is commonplace across the market.

In order to cope with Scenario 3, the company must look towards industry-convergence technologies. More specifically, in order to survive through such unfortunate events, the company must search for other industries where the developed smart grid technologies can be applied, and, once another industry is found, the existing smart grid technology must be adjusted to fit its new industry. Instead of focusing on converging technologies, like the electric vehicle charging system, technologies that have higher potential to be connected to other industries, such as data management technologies, should be emphasized. To conclude, the solution for this scenario is to be selective in choosing the technology to be developed, with one that has high amounts of possible connections with other industries.

Scenario 4 (The Stalemate of the Smart Grid Industry) describes one of the worst cases a company can face, and is as follows: Slow market growth and technology development, and incumbents have begun to cut further investments. Basically, Scenario 4 is the case where the smart grid industry fails to settle as a significant entity of the future energy industry.

The solution to Scenario 4 represses the investments into new technologies and promotes the focus on R&D efforts into technologies that maintain competitiveness. Hypothetically, Hyosung could redirect its focus on its existing power equipment and system solution technologies to overcome these difficulties. The company can place emphasis on technologies that have the potential to enter into the smart grid industry if and when the smart grid industry situation does improve due to the high risks that are involved with continuing investments in new technologies in the smart grid industry.

In summary, it is critical to note that quarterly assessments of changes in technology, market, industry standards, and policy is required to quickly adjust R&D plans accordingly. R&D planning based on scenarios 1 and 2 would result in strong thrusts for developments in the electric vehicle charging domain. From the analysis, the proper assessment of national and global governmental policies on subsidies or regulations and industry trends regarding standardization will further determine whether to direct the company's R&D plans to focus on the development of smart grid modules or platforms, or to focus on innovating disruptive technologies to obtain or maintain competitive advantages. The consideration of global policies is important, in particular, policies of allied countries that may have a conforming effect on local legislations on electric vehicle charging. When considering scenario 1, it can be suggested that the company invest into demand-side management modules targeting the enhancement of user convenience. Under the scenario where the adoption of electric vehicles is increasing, and industry standardization is uniform, R&D plans and expenditures must cater more heavily to meet the consumers' needs and approval. Alternatively, under scenario 2, a manager of R&D can propose the expansion of breakthrough developments into robotic charging stations, renewable energy sources, wireless electric vehicle charging, and energy storage solutions for electric charging infrastructure for competitive advantages over other industry contenders. Such investments would be valuable as the number of users of the electric vehicles increase and continue to desire more accessible, quick, and easy-to-use charging stations. Additionally, heavy investment into energy storage solutions can be suggested for developing charging stations that are able to balance the load of larger and higher power stations. In light of the lacking number of electric vehicle charging infrastructure available for users, it has been stated that battery storage can assist in the acceleration of the construction of charging stations, and consequently boost electric vehicle adoption.

Under the situation where scenarios 3 and 4 are imminent, the company should explore other areas where the incumbent technologies can be applied for new opportunities. Further investing directly into new smart grid technologies could be detrimental to the company. Comprehensive evaluation of existing technologies may provide solutions towards novel innovation. In accordance to scenario 3, it is suggested for the company to converge its electric vehicle charging technologies into areas, such as hydrogen charging stations and data management solutions. Although converging existing technologies into a new industry will require an appropriate assessment of the advantages and disadvantages of the particular area, the accurate selection and transfer of the electric charging technologies can act as a gateway for future developments and prevent developed technologies from becoming obsolete. Assuming scenario 4, the company is suggested to focus R&D plans on existing power equipment and system solution technologies that are closely related to the smart grid industry, such as energy storage systems, data center solutions, and power transmission and distribution infrastructure. These areas are some of the company's most developed technologies, which, with further R&D investments, are sustainable revenue sources whilst encompassing the ability to transition into electric vehicle charging infrastructure in preparations for a possible positive turn for the smart grid industry.

5. Conclusions

In this study, a strategic R&D planning process for the smart grid industry was developed. The planning process is comprised of background research in the smart grid industry, selection of perspective R&D target, STEEP analysis, patent analysis, and TRIZ's nine windows and scenario planning analyses to develop a method and process in establishing a future strategic R&D plan.

The developed planning process was applied to the Hyosung Corporation perspective in the strategic planning of smart grid R&D as a case study. The patent analysis confirmed that Hyosung has devoted significant amounts of investments and research on key smart grid technology areas (i.e., transformers, switchgears, electronic devices, electronic systems, wind turbine systems, solar systems, battery systems, and other related components) since around 2003, and, as a result, already achieved substantial technological competitiveness within the sustainable smart grid domain, including smart power grid, transportation, and renewable energy. With the patent analysis results, TRIZ's nine windows and scenario planning analyses were further performed to produce a strategic R&D plan from the business point of view. From this case study, a strategic smart grid R&D plan for Hyosung to enter the sustainable smart grid industry was suggested and further entered into the sustainable electric vehicle charging technology business. The strategic R&D plan comprises of smart grid communication system, service infrastructure, battery charging duration, public charge station system, platform and module, renewable energy sources, wireless charging, data management system, and electric storage system solution as key technology and business factors. To achieve the goals of the strategic R&D plan, a set of four scenario plans were suggested by taking into consideration technology and growth rates, policies and government subsidies, and system standards of the smart grid charging system as key change agents: Scenario 1, 'The Stabilized Settlement of the Smart Grid Industry'; Scenario 2, 'The Short-lived Blue Ocean of the Smart Grid Industry'; Scenario 3, 'The Questionable Market of the Smart Grid'; and, Scenario 4, 'The Stalemate of the Smart Grid Industry'. The R&D plans in accordance to each scenario were recommended. In scenario 1, the company R&D plan is to pursue investments in development of various modules or a platform that concurs with the current and predicted standards, such as demand-side management modules targeting the enhancement of user convenience. Under scenario 2, the suggested R&D plan is to emphasize a diverse portfolio of different technologies with incremental and disruptive innovations, such as robotic charging, wireless charging, and energy storage solutions, to gain and maintain a competitive advantage in this regulation-less, competitive environment. Scenario 3 is a high uncertainty situation with a strong technological supply-side push, but lacks the market growth and government support. In this scenario, the resulting company R&D plan suggests that R&D endeavors to concentrate on convergent technologies that have the potential to be introduced into new industries, such as data management products and services. Finally, scenario 4 restrains the investments into new technologies and it promotes the focus on R&D efforts into technologies that maintain competitiveness or further investment into incumbent technologies, such as data center solutions and power transmission and distribution infrastructure. The strategic R&D planning process of this study can be used in a variety of different ways within the smart grid industry by reselecting the target to other businesses. Moreover, the planning process can be applicable in various technologies and businesses, because of the independence of any specific subject or business area. Additionally, the planning process may gain high expectations to provide a strategy at the business level and to support an integrated and effective R&D effort.

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