Ph.D. Dissertation in Engineering

Consideration on

Strategic R&D Management of

Public Renewable Energy Technology

Development Program in South Korea

- focusing on diversity and core competency -

대한민국 정부 신재생에너지기술개발사업의

전략적 R&D 관리방안에 대한 고찰

- 다양성과 핵심역량을 중점으로 -

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Consideration on Strategic R&D Management of Public Renewable Energy Technology Development Program in South Korea

- focusing on diversity and core competency-

Dohyoung Kim

Abstract

This dissertation addresses key issues in the strategic management of the public renewable energy technology development program (PRETDP). Strategic Research and Development (R&D) management is important for the PRETDP because innovation in technology is becoming more important for national competitiveness; yet governments only have finite resources. Adopting a resource-based view of public R&D management, this study viewed diversity as a resource that could be studied and used to achieve a better performance of the PRETDP. This study also intended to blend diversity with the discussion of technology differences and core competencies, which are classic subjects of study in strategic R&D management. By adding perspectives on technology differences and core competencies, this study sought to provide practical insights into

the managerial practices of the PRETDP.

The first study aims to provide managerial insights into R&D portfolios by analyzing the effect of R&D team diversity on the outputs of the PRETDP. This study approached diversity from two perspectives: demography and collaboration. For the output variables, this study considered intellectual and experimental outputs. This study analyzed 430 projects completed between 2009 and 2015 in the PRETDP using hierarchical regression analysis. Consequently, this study noted that the demographic diversity of R&D teams in the PRETDP could have an impact on performance in both directions. This study observed that heterogeneous collaboration could have a positive impact on experimental output for all project groups. In addition, this study noted that technology difference was important for project groups with core competency, whereas it had a negative impact on all project groups in the PRETDP.

The second study aims to investigate the relationship between output diversities and outcomes by considering both output quantity and quality. For the output quantity variables, this study used academic publications, patent registrations, prototypes, and certifications. For output quality, this study considered the impact factor, SMART patent index, national certification, and prototype type. Two types of outcome variables were considered as dependent variables: commercialization and employment effects. Using the same data sample as in the previous study and research method, this study noted that output diversity influenced the commercialization and employment effects of all projects.

The third study aims to reinvestigate the relationship between input-to-output and output-to-outcome by considering technology differences and core competencies. Based on the same research model used in the previous two essays, this study added technology difference as a moderating variable to observe the interaction between technology difference and diversity variables. In addition, this study extracted core project groups from the PRETDP to observe differences between all project groups and core project groups in terms of diversity and technology difference. Using the same data sample as in the previous study and research method, this study observed that technology differences worked differently for core project groups and all project groups. This finding is in line with another finding that patent quality is important for core projects, whereas earning certification is more important for all project groups.

The findings from the three studies can provide managerial insights for R&D managers to make strategic decisions on the PRETDP management. The implementation of strategic R&D management begins with the analysis of the accumulated data. By converting

random data into meaningful information, R&D managers can gain insights into strategic decisions. The PRETDP has received uniform assessment as the remainder of the energy technology development program. It does not have a strategic managerial plan for core project management. The findings of these studies can provide valuable information to managerial institutions of the PRETDP to consider changes in their managerial practices.

Keywords: Strategic R&D Management; Public Renewable Energy Technology Development Program; R&D Team Diversity; Output Diversity; Technology Difference; Core competency

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Chapter 1. Introduction

1.1. Research background

Strategic R&D management for public R&D programs has been a significant subject of studies for government officers and research communities aiming for increase in R&D performance [1,2]. As global technology competition is becoming fiercer while government only have finite resource for research activities, public sector became more demanding on finding efficient way of gaining sustainable economic growth and knowledge diffusion through research activities [3,4]. Such trend had made public R&D management agencies to adopt Resource-Based View (RBV) and started to evaluate R&D performance [5].

Public Renewable Energy Technology Development Program (PRETDP) is one of the largest public R&D programs in South Korea that requires more strategic R&D management. With an advent of Mission Innovation, the public expenditure on PRETDP has been constantly increasing through last few years [6] but the rate of renewable energy deployment is still being criticized for not meeting its expectation [7]. Such phenomenon created public concern on inefficient resource allocation in PRETDP, so the adoption of strategic R&D management in PRETDP cannot be timelier than nowadays.

The practice of strategic R&D management starts from a proper analysis on the relationship between resources and performance. However, literatures on strategic R&D management perceived R&D resources with different perspectives [8–11]. By reviewing those studies, it became clear that accounting more factors into R&D strategy could provide more practical solutions for developing management strategy. For example, a lot of previous literatures have studied the relationship between input resources and output [12–14]; some studies were concentrating on energy fields [15,16]; even some were focused on renewable energy [17,18]. Even though many studies have been dedicated on this relationship, this study thinks that there are still many more to be studied. Especially, this study found interest in scrutinizing several aspects of diversity and core competency. In the domain of renewable energy, diversity in research team is a relative new subject of study which could affect the performance positively and negatively. Diversity in research output is even more fresh area of study as majority of previous study only focused on input diversity. Discussion in core competency could also be added in PRETDP by construing core projects as a core competency, which also could be combined with the discussion on technology distance. Those factors can make affluent discussion in the perspective of performance measurement and help developing strategical management plan for PRETDP.

1.2. Problem statement

Despite great increase in public expenditure in PRETDP, the managerial system has not improved enough to make use of collected information from a project to develop more productive discussion on strategic management. To provide technical solution for RE3020 policy, PRETDP should have evaluation system to suit its purpose, and more importantly, it needs to have managerial protocol to enhance performance of core projects.

However, PRETDP is receiving uniformized assessment condition as rest of program, which I would call 'robotomized' evaluation process, even though every program has different objectives. Therefore, program manager cannot tell whether a project has been designed, managed, and evaluated to fulfill the major objective of the program. This means that program managers cannot develop specialized guideline for project evaluation of PRETDP. Unable to provide specialized guideline could raise another concern for project assessment, as the authority of project evaluation has been given to outsourced committee. Standard protocol for public projects evaluation stipulates that funding agency should employ outsourced committee to avoid illicit gains and improve professionalism. But, since outsourced committee members are not familiar with objective of PRETDP nor portfolio management, they can only consider technical factor of the individual project if proper guideline at program level is not given to them. This could create makes evaluation committee to underperform which could lead to failure on meeting goal of a program and could also lead to dissatisfaction of project applicants. Such dissatisfactions are not ideal for PRETDP because it makes them questions about professionalism of funding agency. This can bring down reputation of PRETDP, act as a brake pedal for budget increase of a program when it is in need. Therefore, it is important for program managers to make best use of acquired information on projects and distinguish the managerial points between diverse groups of projects.

1.3. Research objectives

As outlined in the problem statements, the major aim of this study is providing information for decision makers in PRETDP to develop better management strategy. This study addresses its research objectives by presenting three articles, each of which deals with a separate problem.

The first article aims to provide managerial insights for R&D portfolio by analyzing the effect of R&D team diversity on outputs of PRETDP. This article approached diversity with two different perspectives: one as a demography and another as a collaboration. Demographic diversity can be break down to diversity in gender, age, educational background, and educational level. Collaboration diversity can be divided as homogeneous collaboration, heterogeneous collaboration, and non-collaboration project groups. For output variables, this article considered intellectual and experimental outputs, which are going to be independent variables for next article. This article compares similarity and difference of relationship for both outputs to analyze how R&D team diversity works with R&D outputs.

The second article aims to investigate relationship between output diversity and outcome with consideration of both in output quantity and quality. For output quantity variables, this article used academic publication, patent registrations, prototypes, and certifications. For output quality, this article considered Impact Factor, SMART patent index, national certification, and type of prototype. Two types of outcome variables were considered as dependent variables: commercialization and employment effect. This article also provides discussion on how quality, quantity, and diversity of outputs work with both outcomes.

The third article aims to provide implications on strategic R&D management practice of PRETDP by adding discussion on technology difference and core projects' management from previous two essays. Based on same research model of previous two essays, this article added technology difference as a moderating variable to observe interaction between technology difference and diversity variables. Also, this article extracted core projects' group from PRETDP to observe difference between all projects' group and core projects' group in terms of diversity and technology difference. This article should provide overall implications for both groups that could be applied to reform project evaluation process and objective management.

1.4. Research question

Based on the research problems and research objectives, this study formulates an overall research question with three subsets:

The overall research question and the two main research questions regarding strategic management and renewable energy R&D performance are as follows:

- ✧ What are strategical management points for PRETDP and core projects with respect of R&D team diversity, output diversity, and technology difference?
    - ➢ What factors of R&D team diversity affect intellectual and experimental output of PRETDP?
    - ➢ How quality, quantity, and diversity of outputs affect commercialization and employment effect of PRETDP?
    - ➢ Does technology difference play any distinct roles between all projects' and core projects' group of PRETDP?

The first subset of research questions regarding "analysis on the relationship between R&D team diversity and output in PRETDP with respect to demography and collaboration" are as follows:

- ✧ Does diversity in R&D team makes different impact on intellectual and experimental output of PRETDP?

  - ➢ How does diversity of R&D team demography in PRETDP relate to the intellectual and experimental output?
  - ➢ How does diversity of R&D team collaboration in PRETDP relate to the intellectual and experimental output?
  - ➢ Are there any control factors of R&D team or project affect the intellectual and experimental output of PRETDP?

The second subset of research questions regarding "analysis on the relationship between output diversity and outcome in PRETDP: focusing on output quantity and quality" are as follows:

- ✧ Does diversity in R&D outputs makes different impact on commercialization and employment effect outcome of PRETDP?

    - ➢ How does diversity of outputs in PRETDP relate to the commercialization and employment effect outcome?
    - ➢ How does quality of outputs of PRETDP relate to the commercialization and employment effect outcome?
    - ➢ How does quantity of outputs of PRETDP relate to the commercialization and employment effect outcome?
    - ➢ Are there any control factors of R&D project affect the commercialization and employment effect outcome of PRETDP?

The third subset of research questions regarding "Consideration on the strategic R&D management of PRETDP: focusing on technology difference and core competency" are as follows:

- ✧ Does diversity technology difference moderate different relationship between all projects' and core projects' group of PRETDP?

  - ➢ How does technology difference moderate the relationship between input diversity and outputs of PRETDP?
  - ➢ How does technology difference moderate the relationship between output diversity and outcomes of PRETDP?
  - ➢ What are differences characteristics between all projects' and core projects' group of PRETDP in terms of diversity and technology difference?

1.5. Research outline

This study is composed of six chapters. Chapter 2 is literature review regarding to theory of strategic management in the context of diversity control and core competency. The purpose of this chapter is to provide sufficient background literatures on why studying strategic R&D management of PRETDP is important and what theoretical background it can refer to for better management of them.

Chapter 3 and Chapter 4 is about empirical study on strategic management of PRETDP in the perspective of input-to-output and output-to-outcome. Chapter 3 analyzed the relationship between R&D team diversity and output in PRETDP with respect to demography and collaboration. For the demographic diversity, gender, age, educational background, and educational level were considered. For the collaboration diversity, University-Industry-Government Research Institute (GRI) were analyzed with grouping of homogeneous and heterogeneous collaboration. Chapter 4 was devoted to reveal relationships between R&D output diversity and outcome. R&D output were divided into intellectual and experimental output. Academic publications and patent registrations were considered for intellectual output, whereas prototypes and certifications were considered for experimental output. Also, variables regarding to output quality are also controlled.

Chapter 5 expands discussion from Chapter 3 and 4 by adding technology difference as a moderating variable and by comparing core projects' group with all projects' group. This chapter reuse variables from Chapter 3 and 4 but add new moderating variable and new group onto it. This article provides overall discussion of Strategic R&D management of PRETDP.

Then, Chapter 6 summarizes the overall results, addresses the study's implications and contributions, and concludes by outlining the study's limitations and the outlook for future studies.

Chapter 2. Literature Review

2.1. Public Renewable Energy Technology Development Program (PRETDP)

Public Renewable Energy Technology Development Program (PRETDP) is a public technology development program for renewable energy in South Korea, which has initiated from 2006. PRETDP is one of the largest government R&D program accounting for 1 % of 20 trillion in KRW South Korea's annual public R&D program budget. The annual budget for PRETDP is 283 billion in KRW, which is about 3.8 times larger than sum of annual budget assigned for Clean Coal Technology Development (19 billion in KRW) and Nuclear Technology Development (56 billion in KRW). This shows how much Korean government has interest in renewable energy technology development. Therefore, one could say that studying performance of PRETDP should be a grave matter due to its massive budget scale. PRETDP has its grounds on '*Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy'* and '*Electricity Utility Act,'* both founded by the Ministry of Trade, Industry, and Energy (MOTIE). The subprogram for PRETDP is majorly categorized by the energy sources: photovoltaics, solar heating, wind power, hydropower, marine energy, fuel cell, hydrogen, biogas, biowaste, geothermal, Integrated Gasification Combined Cycle, renewable energy fusion, and biogas-hydrogen recharging station [19].

Since PRETDP contains technologies from multiple renewable energy resources, it also consists various objectives to support government's needs. One of the main goals is the localization of key technologies. It is one of important goals of PRETDP because such activity could nurture technology competitiveness for domestic renewable energy enterprises and stabilize domestic value chain. Technologies related to hydrogen production and storage has also been added as a goal, following recent announcement of *Hydrogen Economy Activation Roadmap*. This roadmap announced technology related to production of 'green hydrogen' and high-efficient fuel cell system will be developed through government R&D program. There are other goals, too. PRETDP is also interested in solving problems within communities related to the deployment of renewable energy sources, such as reducing light refection on solar panel or low-frequency noise in wind turbine. Application of technologies related to Internet-of-Things and Big Data for enhancing monitoring system is also development goal for this program [20]. In addition, developing technologies for the reliability of grid connection for renewable energy sources are also covered in this program.

2.1.1. Why strategic R&D management gains attention in PRETDP?

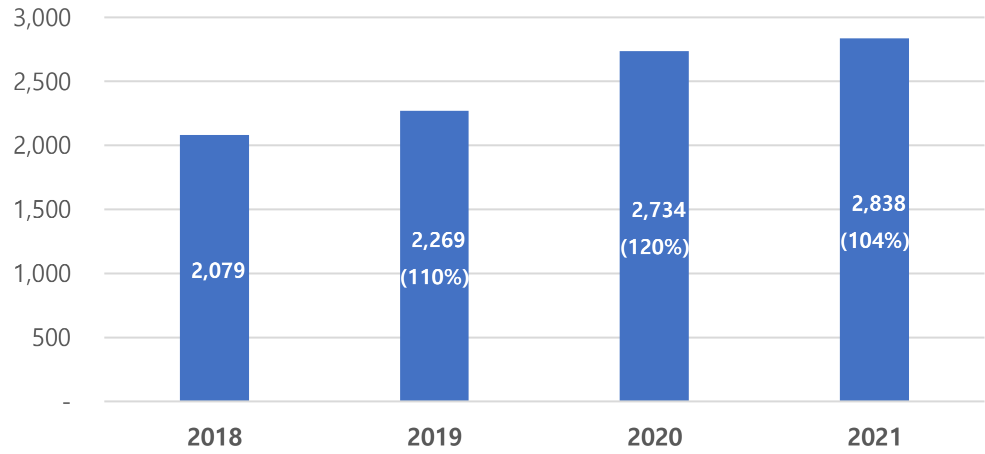

Figure 1. Annual budget increase in public RE technology development program

As shown in Figure 1, PRETDP has experienced the increase in budget during last few years. Since the advent of Mission Innovation, which is a global initiative established after the Paris Agreement to promote clean energy innovation, the increase in public renewable energy R&D investment has been a global trend [21]. To be more specific, global RD&D investments have increased by USD 4.6 billion between 2016 and 2018, a 55% increase from the investment baseline in 2016. To fulfill its part in clean energy innovation, South Korea has been made more investment in PRETDP. To meet its expenditure, more projects had to be designed and deployed in short term.

If last few years were busy promoting more research activities, the time may has arrived to review the past expenditure and provide feedbacks to make better investment in the future. It is quite common in public sector that radical budget increase often led to inefficient resource allocation. As shown in Figure 2, the Armey Curve – proposed by Scully (1995) – displays how public expenditure could become inefficient beyond an optimal point [22]. Thus, people with decision-making authority are tasked with preventing such inefficiency or misallocation of resources by assessing the performance of their investments and relocating resources to maximize social benefits such as economic growth [22,23].

This notion is also applicable to public R&D sector [24], as R&D is no longer considered to be unstructured and unmanageable activities [25]. In the era of severe market competition and rapid advancement in technology, competitiveness in public R&D can influence the national competitiveness. Therefore, R&D activities are perceived to be more efficient by minimizing cost, risk, and project time through proper management [26]. The performance-based budget allocation approach has proven its effectiveness, as more and more countries and sectors have employed this approach [27–30]. This system could be applied to PRETDP and used to inform policymakers to reallocate public R&D resources to more efficient way.

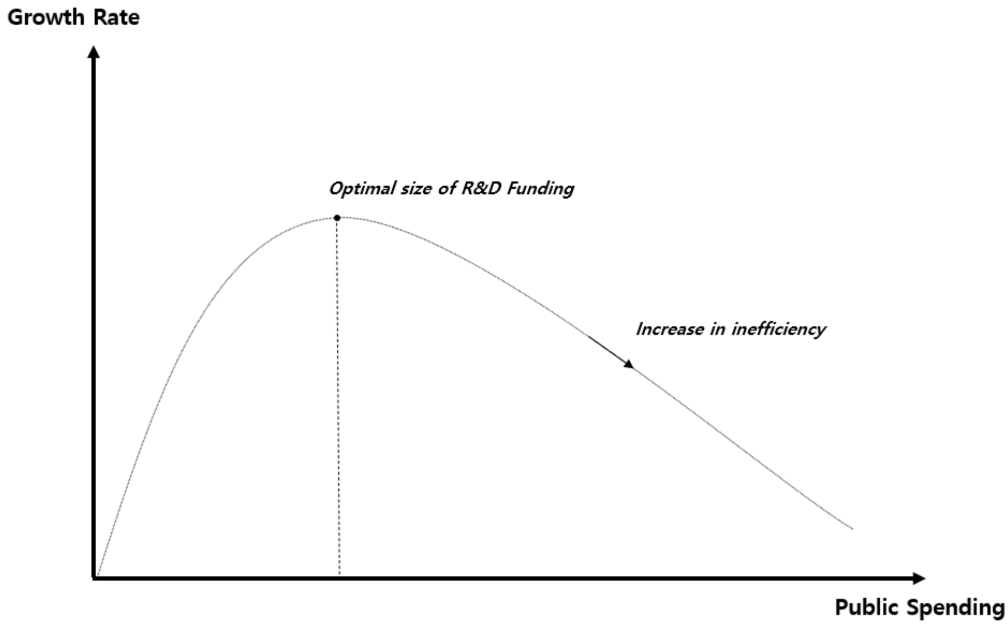

Figure 2. Application of Scully's Armey-Curve on Public R&D Expenditure

2.1.2. Importance of core project and technology difference management

To apply strategic management system in PRETDP, one should start how to align with higher basic plans. *Science & Technology Basic Plan* highlights nurturing technology fusion between various fields and promoting disruptive innovation. *Energy Technology Development Basic Plan* emphasizes improvement in project commercialization rate through cooperation with various entities such as private, public enterprise, or government research institutions. *Renewable Energy Technology Development and Supply Plan* signifies expansion in renewable energy supply, demanding R&D plan to prioritize the improvement in power efficiency and cost reduction. To meet with such expectations from higher basic plans, the managerial side of PRETDP need to develop more strategical management system for various outputs and outcome to accomplish its goal.

Table 1. Comparison of South Korea's national R&D programs in power generation

Category[1]	**Objectives**	**Goals**	**Performance Index**
Renewables R&D 	• **Increase deployment of new RE products**, such as PV or Wind Power system, to support RE 3020 • **Develop high-efficiency** fuel cell and hydrogen products to found hydrogen-based industry eco-system	• **(PV)** Develop new generation RE product possessing high added value potential • **(Wind)** Develop new products reducing LCOE • **(Fuel Cell)** Develop new product with stability and low cost • **(Hydrogen)** Develop projects that could support enhancement in infrastructure of hydrogen production, transport, storage	• **Intellectual output** • **Commercialization rate** • **Employment Effect** • Contribution to RE production
Nuclear R&D 	• **Improve core technologies** for nuclear plant to provide reliable energy supply • **Develop safety and decommission technologies** to improve commercialization	• **(Safety & Advancement)** Develop risk management facilities from natural cause and man-made hazards • **(Environment & Decommission)** Develop practical technologies to decommission Gori power plant and more	• **Intellectual output** • **Commercialization rate** • SME's nuclear power plant operation registration ratio
 **Clean Coal R&D**	• **Improve core technologies** for curtailing CO2 emission and providing reliable energy supply	• **(Core Technology)** Improvement in existing facility and reduction in CO2 emission • **(Micro-dust)** Technologies relating to reduce micro-dust • **(Testbed)** Developing infrastructure to support field test for SMEs	• **Intellectual output** • **Commercialization rate** • Royalty

1 Image Referenced from South Korea's *4th Energy Technology Development Basic Plan (2019~2028), MOTIE*

As shown in Table 1, the main objective of PRETDP is developing new products that could help renewable energy generation to reach 20% by 2030, known as *RE3020* policy. According to data retrieved from National Technology Information Service (NTIS) registered in 2020, around 31% of projects in renewable energy technology development is concentrating on new product development. New product development in renewable energy technology is about creating a product with higher power generation efficiency or lower module production cost by developing unconventional techniques. This is what differentiates renewable energy technology from conventional power generation technology, mostly nuclear and clean coal, where improvement of process or coping with environmental and safety issues are prior concern for their technology development program.

One may think that "*isn't all renewable energy technology development about improving efficiency or cost reduction?*" But as demonstrated at the beginning of this chapter, PRETDP contains many types of projects relating to environmental or safety issues, which could be more grave matter for project deployment. Wind power, for example, has been going through many complaints on low frequency noise from neighborhoods near wind power plants [31]. Photovoltaics are facing similar predicaments due to light reflection, especially for those who live in densely populated area [32]. Solving those problems are a part of role for PRETDP. This requires more of practical solution by applying knowledge from similar case in other industry fields. Also, these projects may want to follow standard protocol or to seek for certificate from public institution could improve its credibility so that deployment process could be accelerated.

To fulfill key role of PRETDP, however, it is important to provide technologies to replace the portion of power generation comes from conventional energy sources. Normally, the word “efficiency” or “cost reduction” indicates the improvement of pre-existing products. However, in PRETDP, those words indicate new product development because the ultimate goal of PRETDP is developing a device with better power generation efficiency or with less use of space by using new methods or materials [33]. This requires different approach from cost reduction in manufacturing labors or slight modification of pre-existing products. In photovoltaics development, for example, most of solar power generation technologies is reaching close to its theoretical efficiency so that increase of generation efficiency in lab scale by just few percentage require at least a decade [34]. Increasing efficiency in renewable energy source requires a great amount of innovation but could have a disruptive impact on market, so they need a special attention from R&D program managers to achieve best performance.

Therefore, strategic management system of PRETDP should have different managerial tactics for core projects and overall projects. To do so, managers in PRETDP should revise their input and output resources to observe how those resources could affect the performance.

2.1.3. Importance of R&D team diversity management

There are numerous input resources to review in R&D, but as pointed out in the first chapter of this study, basic characteristics of projects such as government expenditure, number of personnel, or project duration often covered in numerous studies [12–14], even in the field of energy [15,16], and renewable energy [17,18]. So, this study is focusing on characteristics of R&D teams as they are the core asset of research projects that could provide innovation seeks in PRETDP. Renewable energy industry seeks for unique products that could transform the traditional energy system, so managers of PRETDP seeks for projects that could deliver such innovativeness. These products should be able to increase efficiency in power generation or lower Levelized Cost of Energy (LCOE) with new methods, which are often unable to be found in the current market. For example, silicon solar panel research and development in photovoltaics already reaching close to theoretical efficiency so that research community trying out silicon tandem cells with various materials. These technologies also seek for applicability in cars, ships, farms, or water surfaces. Since technological and systemic innovation is continuing to be important, unique solution in renewable energy RD&D will continuously be demanded [21]. Diversity is often known as a key to an innovative solution; therefore, if one could understand it and exploits it to be better used for performance, the overall performance of PRETDP will also be increased.

So, studying diversity in R&D projects could result technical leap, but this is not the end of it. Knowing how to embrace diversity could also help increase public acceptance. Over past few decades, public engagement has become a keystone of many different sectors of policy and decision making, encompassing the environment and sustainable development, science and technology, spatial planning, and more recently climate change [35]. One of these days, instead of uniformly receiving electric bills from electric company, South Korea may be able to do person-to-person (P2P) electricity trade, just like some of developed countries do now. But, if such system is made by homogeneous social group, it would be difficult to gain approvals from various communities. PRETDP is the introductory stage of all renewable energy technology development. So, if more different group of researcher engages in this stage to provide various social opinions, such technologies could be more adoptable to community at deployment stage. Borrowing the word of *Plato*, "*The beginning is the most important part of the work*;" so, PRETDP should deal with diversity as the first step of the renewable energy technology deployment.

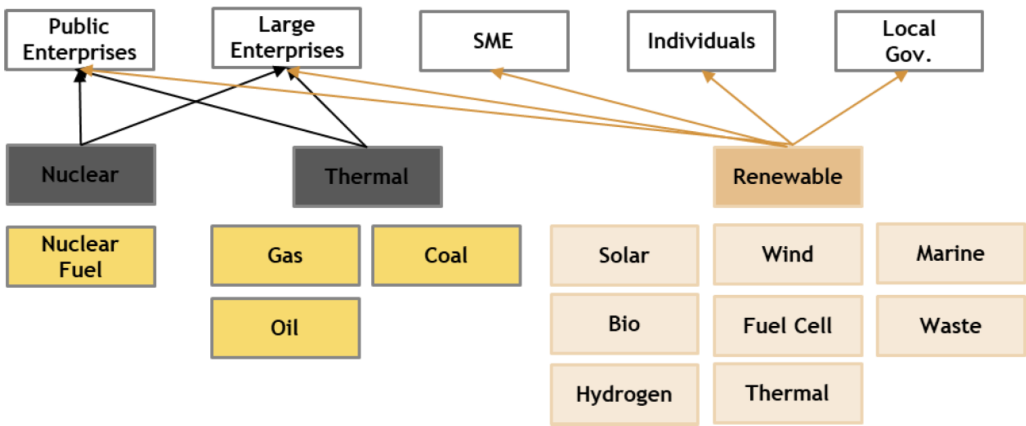

Figure 3. Energy Industry Structure of South Korea

Fortunately, public renewable energy R&D in South Korea possess many diversity capabilities in its structure. Figure 3 illustrates the structure of energy industry in South Korea. Traditional power sources relying on centralized energy supply system with few enormous power plants. These plants are managed and supervised by few public and large enterprises; therefore, if public projects want to be commercialized, R&D collaboration with those entities are critical. On the other hand, renewable energy has many R&D cooperation channels because these power plants could be operated by many different entities such as local governments, private corporations, and even households. Also, renewable energy is composed of various energy sources often involves hybrid system, as shown in, so that involvement and collaboration between various expertise with different skills sets are mandatory. Although some of these technologies share similar technical backgrounds, many are requiring very different skill sets so that more job opportunities are given to expertise with various educational background, especially to solve unemployment issues [36]. In such environment, researchers and R&D manages must cope with diversity in workforce and organization.

So, diversity is an asset to research and development activities, yet simply promoting it would not create a positive synergy in terms of performance. Diversity is known to be a stimulator of research performance, yet many empirical studies agreed that excessive diversity could be harmful to performance [37–39]. These studies make their arguments based on the notion that excessive technological diversification would increase R&D costs come from the heavy costs of coordination and integration of technological knowledge across a variety of technology disciplinary frontiers [40]. Therefore, abundancy of diversity in PRETDP should be scrutinized into details to observe the side effect of it and find a better way of exploiting it.

2.2. Applying strategic R&D management in public sector

Embracing the idea of efficient resource allocation, the public R&D management has been evolved in a way to intensify the control over research projects which can be explained by management control behavior, the part of the organization control theory. Organization control indicates a behavior or action that induces organization members to act in a way to achieve organizational objective [41]. Management control is control activities of managers that forces teams or an individual to perform specific actions or to avoid particular actions so that their destined target could be reached [42]. In broader sense, management control can be considered as comprehensive evaluation process on project plans, executers, and performance [43]. The control behavior of government on public research projects is a process of controlling researchers to attain better performance by adopting measurement indicators.

Although introducing performance measurement indicators in public research projects used to seem inappropriate, circumstances has changed for government to develop them for improvement in performance. R&D once thought to be unstructured activities filled with creativity and uniqueness [25]. However, as the market competition became intensified and advancement in technology became essential for national competitiveness, policy decision makers have started to search for ways to manage public research projects more effectively and efficiently. Fulfilling demands of policy decision makers, management of public R&D projects has been evolved to minimize cost, risk, and project duration [26]. Such policy moves forced public R&D performance measurement indicators to be improved in a way that researchers could have more objective and fair assessments.

2.2.1. Adoption of Resource-Based View

Accumulation in knowledge had let our world to leap up from industrial-based economy to knowledge-based economy. The "knowledge-based economy" is an expression coined to describe trends in advanced economies towards greater dependence on knowledge, information and high skill levels, and the increasing need for ready access to all of these by the business and public sectors [44]. Nobel prize winner Simon Kuznets (1966, p. 6) puts this notion as: "an increase in the stock of useful knowledge and the extension of its application are of the essence of modern economic growth" [45]. This new trend of economy cannot be functioned by itself but requires interactive processes, which can be created by exchange of knowledge both internally and externally. This stock of knowledge became unwieldy so that the significance of knowledge management has been emphasized through broad literatures in innovation and policy research.

Knowledge management refers to identifying and leveraging the collective knowledge in an organization to support innovation [46]. There exists a mutual agreement that knowledge and innovation is the competitive strength needed for successful organization [47–49]. Innovation involves both fixed and intangible investments. Innovation is subject to spillovers. Innovation involves the utilization of new knowledge or combination of existing knowledge. Most importantly, innovation aims at improving a firm's performance by gaining a competitive advantage [44].

R&D activities involve complexity and uncertainty so that outcome of them is often unpredictable. Therefore, R&D activities rely on highly skilled workers, on interactions with other firms and public research institutions, and on an organizational structure that is conducive to learning and exploiting knowledge [50]. Mostly, sustainable competitive advantage of organization needs an organization to continuously differentiate its products and services from competitors [51,52]. Much innovation activity is not R&D-based, however, R&D plays a vital role in the innovation process in a way that make an organization to take action to differentiate itself from competitors [53].

One of major issue in public sector is assuring fairness and R&D activities are not exclusive on that matter. Traditional diversity management consists several aims such as understanding cultural differences, preventing discrimination, encouraging cultural interactions, and enhancing cultural development and leadership practices in the organization [54,55]. Particularly in the public sector, diversity management is well executed by equal employment opportunity (EEO) or affirmative action (AA) policies compared with diversity management in the private sector [56,57].

Another point of view regards diversity as a resource, seeking a way to manage it to achieve performance enhancement. Resource-based View (RBV) highlights the importance of resources and capabilities in supporting organizational survival, growth, and overall effectiveness [58,59]. RBV was originated from the private sector but it is increasingly being applied as a theoretical basis for studying public sector, which also rely on resources and capabilities to deliver public value to key stakeholders [60,61]. From perspective of RBV, diversity can be a valuable, rare, and inimitable resource that enhances organizational competitiveness [62].

In public R&D, RBV should be the basis for diversity management because fairness alone is becoming not enough for appealing the public to limited government resources.

Resource allocation is a critical issue for many fields since government resource is finite [63,64]. Fairness is about providing equality but it cannot be freed from controversy of reverse discrimination [65]. Therefore, it is important to recall why government invest its limited resource in R&D. Government allocate public resource on R&D in expectation of achieving technical competitiveness as it become an crucial index for not only national competitiveness but also for sustainable economic growth and knowledge in society [3,4]. Especially for South Korea, public R&D has been played an essential role for the rapid growth of economy during last few decades so that South Korean is allocating great amount of its expenditure on public R&D. If one could provide evidence whether diversity could support this goal based on R&D performance enhancement, it would be much easier to getting more public to agree on government investment on public R&D.

2.2.2. Management control and R&D team diversity

Diversity could stimulate the R&D performance in a positive way by controlling its usage in R&D environment. By analyzing how each factor of diversity contribute to the performance, R&D managers could control each factor to be either promoted or restrained. Considering public R&D portfolio as a gigantic organization, the element that composes the

R&D portfolio – which are individual, research organization, and research projects – could be either positively or negatively affected by diversity; therefore, understanding the characteristics of diversity is important for its management.

There are many theories explain the positive and negative effect of the diversity. It is important to understand these theoretical backgrounds and use them to effectively manage public R&D portfolio. Some views diversity as a positive factor for an organization's performance because diversity could add new perspectives and experiences to the group. The cognitive diversity hypothesis explains how diversity benefits organizational outcomes. Previous study shown that physical diversity characteristics such as race, age, or sex (also known as bio-demographic diversity) positively influence performance because team members contribute unique cognitive attributes based on their experiences stemming from their demographic background [66]. Meanwhile, some views the diversity as a negative factor for organization's performance because difference makes disconnection and raises in communication cost between diverse groups. The similarity-attraction paradigm explains how diversity can have negative outcome for an organization. Previous research has shown that members who belong to diverse work units may become less attached, are absent from work more often, and are more likely to quit [67]. Another study showed that when organizations use recruitment materials that target sexual minorities, the attraction of study participants weakened among heterosexuals [68]. Social identity theory is another explanation of why diversity may have a negative outcome. Social identity theory suggests that when we first come into contact with others, we categorize them as belonging to an in-group (i.e., the same group as us) or an out-group (not belonging to our group) [69].

Controlling diversity is about creating desirable culture. Organizational culture could be a unifying force, a normative glue that binds people together [70]. Therefore, diversity could be either promoted or restraining based on managerial evaluation on certain factor of diversity. First strategy would be promoting diversity that forms a positive relationship with the performance. From the perspective of industrial anthropology, informal relationship within work groups are very important [71,72]. This relationship is built upon given nature of an organization; therefore, the natural informal relationship will be developed when diversity is well promoted in organization. However, if the diversity passed through threshold point, it might no longer be effective so that proper re-assessment should be made to monitor the effect of diversity. Second strategy would be restraining diversity that forms a negative relationship with the performance or provide a supporting tool for it. The managerial view treats the culture of an organization as an independent variable that can be manipulated to control deviant behavior [73]. By providing interpersonal networks to support individual interpretations of experience, an organizational diversity could be functioned to alleviate negative effect of it [74].

2.2.3. Technology difference and core competency

Strategic R&D management is closely related to the management of technology. Although there are no simple rules for public R&D management [1], strategic R&D management is about figuring out how to do better portfolio management. In this perspective, it is significant for R&D managers to know how different technologies are [75] and what are core technologies [76].

Core competency and technology difference is intricately linked together on making strategic decision, because technology difference could be used as a tool to distinguish a core competency from rest of R&D portfolio. Core Competencies (CCs) can be defined as consisting of bodies of technological expertise, which is often used in product and process, and the organizational capacity to deploy that expertise effectively [37]. Depending on its context, CCs can be construed as technological character or subdivision of an organization. As Tallman (1996) suggested, they are embellished and strengthened through continued use, meaning that they are subject to positive returns, and are therefore to some extent firm-specific and non-transferable. If we expand such definition to research activities, CCs can be discussed in the context of firm's strategic decision for portfolio management, or for project management of R&D activities. From this perspective, firms can efficiently accumulate and strengthen its technological knowledge by applying different managerial metrics on small number of core technology fields [77]. The academic discussion on technology difference is derived from the idea of the exploration and exploitation as well. In organizational studies, exploration and exploitation are often used to explain activities of organizations seeking a competitive advantage over others [78]. Exploration strategies are associated with search, discovery, experimentation, and the development of new knowledge. In contrast, exploitation strategies involve activities that seek the refinement and extension of existing knowledge and are associated with convergent thinking [79]. This is a two different managerial decision for technology development which could significantly affect the technology development strategy.

2.2.4. Diagnostic system to measure R&D performance

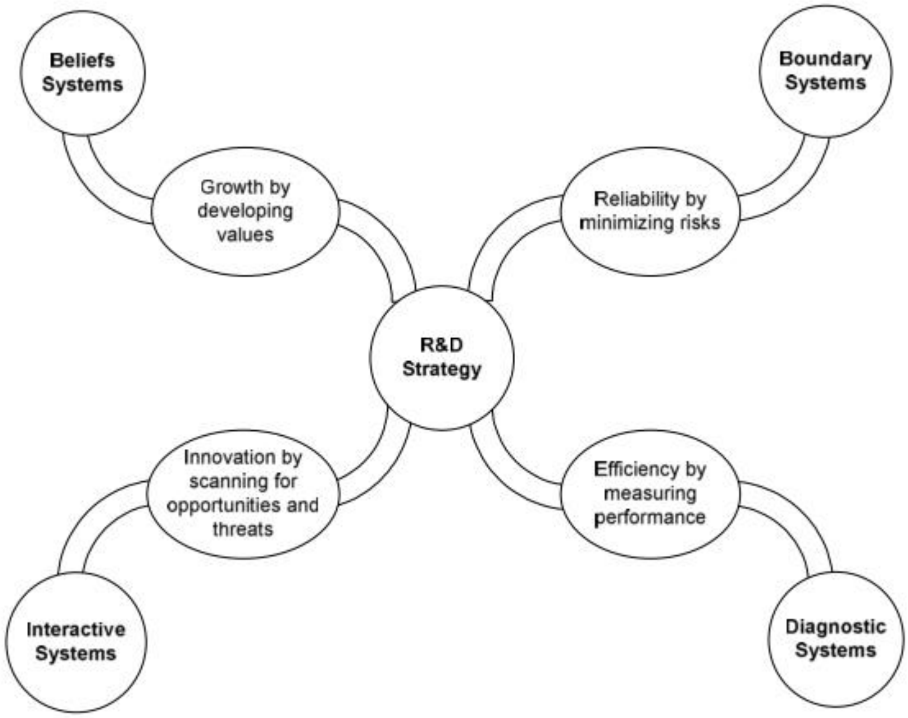

Figure 4. R&D Control Lever Model proposed by Simon (1994)

The R&D management has been evolved in a way to intensify the control over research projects which can be explained by management control behavior, the part of the organization control [80]. The discussion on the effective R&D management was initiated by Freeman (1966), when he said, "if we cannot measure all of the information generated by R&D activities because of a variety of practical difficulties, this does not mean that it may not be useful to measure part of it" [81]. Management control research were thrived in the field of accounting and strategic management and researchers in these fields recognized there are several subsystems [82–84]. These findings put together by Simon (1994), when he proposed an influential model of management control composed of what he termed levers of control — beliefs systems, boundary systems, diagnostic systems, and interactive systems as shown in Figure 4 [80,85,86].

In the context of R&D organizations and knowledge management, these four types of control systems represented the policies, procedures, and technologies that influence the cultural norms and behaviors of individuals and groups [80]. According to summarization of McCarrthy (2011), the beliefs systems define, communicate, and enhance the research objectives and scientific principles that support the organization. The boundary systems provide the rules and limits that delineate acceptable types and levels of R&D activity. This system also enables the evaluation and prioritization of research projects and resource allocation considerations. The interactive systems promote communication, learning and the emergence of innovative ideas, objectives, and even strategies. Diagnostic systems measure the outcomes of R&D tasks or processes. This system provides so-called 'error controlled' feedback for monitoring and adjusting R&D activities & outputs align with strategic goals.

Among these four types of systems, diagnostic system gained most of attentions of researchers. Although diagnostic system alone does not represent entire organization control behavior, it is surely the most important function of the organizational control that could enhance the R&D output and outcome by providing feedbacks reaped from the R&D assessment process.

Table **2** shows previous literatures on diagnostic system. Early studies, conducted through 1980s and 1990s, were concentrating on the validation of performance measurement; they argue that R&D performance measurement should consider different stages, types, and technical and commercial performance of R&D activities [87–90]. Based on these early studies, researchers have started to made efforts to measure R&D performance by type of activities [91–93]. For instance, Chiesa (2009) have conducted empirical studies on Italian firms to find what are the criteria should be employed to design more effective performance measurement system. Another study conducted by Lazzarotti (2011) argues that new framework for performance measurement is needed to cover financial, customer, innovation and learning, internal business, alliances, and networks aspects. Reviewed all these literatures, it has become clear that performance measurement needed to be studied in the context of technical and commercial performance and different R&D stages; and the performance measurement system periodically needs to be evolved into a new model.

Table 2. Review of empirical studies within the diagnostic system literature

Article	Analysis	Findings
Schainblatt (1982)	Literature and company survey that compared the use of R&D productivity measurement systems	Systems should differ according to research activities and development activities, and overall R&D goals
Cordero (1990)	A study the links between firm level R&D investments, productivity, and reward allocation	A model that combines technical and commercial performance and specifies how measures vary according to organizational levels and process stages
Bart (1993)	Interviews with R&D managers in large companies on the tightness or formality of their control systems	The importance of balancing formal and informal controls, in line with R&D goals
Werner & Souder (1997)	Survey to understand measurement philosophy and perceived usefulness of measurement	Control system design is dependent on control aims, type of R&D activity, data availability and cos
Soderquist & Godener (2004)	Use and impact of performance measurement on decision-making and operations	Using performance results will improve R&D relevance and coherence, decision-making, and employee motivation
Chiesa, Frattini, Lazzarotti (2009)	Investigating the influence exerted by the type of activity being measured on the design of the Performance Measurement System	Designing and using two different Performance Measurement System for research and new product development can be a valuable alternative
Lazzarotti (2011)	the technological and competitive environment has dramatically changed so that Performance Measurement System must be evolved as well	Need of new framework covering financial, customer, innovation and learning, internal business, alliances, and networks.

[1] Reconstructed from McCarthy & Gordon (2011)

2.3. R&D Performance Measurement

The literature of R&D performance measurement is derived from the R&D management. The R&D management is the function of leading and designing processes that confirms smooth transfer of new knowledge, management of research organizations, and also creating a communication channel for other departments and organizations involved in the innovation process [95–97]. R&D management has been evolved through generations to enhance knowledge management in research organizations. The first generation of R&D management is considered between 1950 and mid-1960s. This is the period where R&D was concentrating only increase in productivity [98]. The second generation took place from mid-1960s to early 1970s, where the concept of demand and supply was introduced and marketing efforts were emphasized [99]. The third generation was introduced from late 1970s to 1980s, where the increase of efficiency in R&D activities are starting to gain attentions in research communities [100]. Also, portfolio view in R&D management is introduced to lead the market success and balance the risk of organizations [101]. The fourth generation was introduced from early 1980s to mid-1990s. At this period, management realized that informational loops are now inter-organizational and flexible evaluation model is now required. In the past, R&D activity was considered as linear model and the upper hierarchy of the corporation periodically conducts internal evaluations of the efficiency of the R&D laboratories [102]. But within the fourth generation, the scope of R&D has moved to collaborative research; technological alliance between corporate users and producers became widespread; government laboratories and universities increased enormously their links to industry; and interaction with the business environment like suppliers, distributors, customers, competitors came into consideration [103].

The appropriate next question would be where we are now on R&D management. Some considered later stage of fourth generation as a fifth generation, where knowledge became crucial asset to be managed [104]. The R&D process can primarily be considered as a knowledge management process, because it transforms information on technological advancements and market demands into knowledge which can be used for developing new product concepts and process designs [105]. Although there may be a disagreement on the stage R&D generation, the mutual agreement would be that knowledge management is growing to be much more significant and it will be more in the future.

But what is more important than which generation are we in on R&D management is whether we have a proper tool to point out managerial problems. The more critical issue is that we are not even fully realized the major purpose of fourth utilization to suit the different purposed R&D activities. Previous studies are concentrating on general purpose solution, rather than R&D specialized solutions for specific area [106]. These studies were tending to have concern in generic knowledge functions such as data registration, storage, and retrieval. As previous study pointed out, if we are truly seeking for the evolution into the next generation of R&D, restructuring the system of R&D management architecture and re-designed for targeted program must be done. These knowledges should not only store and retrieve easily, but also managed and controlled to suit the purpose of information users. In this context, the role of R&D performance measurement system is becoming more essential since it could diagnose the problem of current state of R&D management and provide feedback to decision makers to create changes.

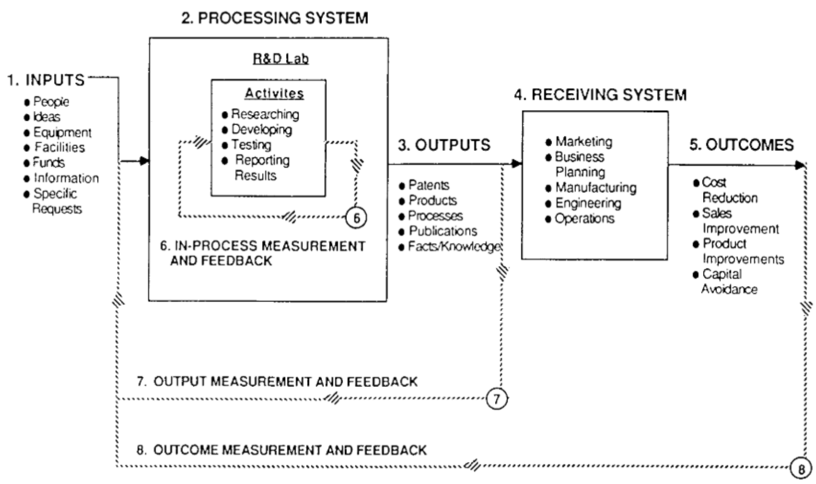

Figure 5. 1st generation R&D performance measurement model (Brown & Svenson)

To develop R&D performance measurement system that could make a proper diagnosis, it is important to include indicators reflecting what could be accomplished through the execution of research project both in quantitative and qualitative terms. These indicators are based on the idea of Brown and Svenson's R&D lab system [107]. Brown and Svenson saw R&D as a one system that has components of input, processing system, output, receiving system, outcome, and feedback. Many of current performance measurement indicators are based on Brown and Svenson's idea. The United States had implemented STAR METRICS[2] to define causal relationship between public investment and healthcare R&D performance [108]. National Institutes of Health (NIH) use STAR METRICS to collect information on knowledge (ex. number of articles, citations), social influence (ex. health promotion, environmental influence), workforce (ex. number of employments), and economic growth (ex. patents, number of start-ups). Canadian government also employs input-output index to evaluate publicly funded research projects [109]. The government of Taiwan defined

[2] STAR METRICS (Science & Technology for America's Reinvestment: Measuring the Effects of Research on Innovation, Competitiveness and Science) is a data platform, constructed around 2010, that is being voluntarily and collaboratively developed by U.S. federal science agencies and research institutions to describe investments in science and their result [108]

criterion for public R&D project assessment as input-output relationship, technology transfer, and other ripple effect [110] South Korea, one of countries that government have great interest in improving public R&D assessment system, had even made guideline for the national R&D standard performance indicator. South Korea made clear description for each component of indicators which is shown in .

Table 3.

Table 3. Definition of Performance Indicators for Public R&D in South Korea

Indicator Type	Description
Input	Inputs used in the R&D process such as financial resources, in-kind, personnel, equipment, etc.
Process	Activities carried out within an organization that have been promoted to convert raw materials into outputs or to services
Output (Quantitative)	Quantitative performance output created during the process of R&D (ex. number of academic publications, patent registrations, etc.)
Output (Qualitative)	Qualitative performance output created during the process of R&D (ex. impact factor of published articles, quality score of patents, etc.)
Outcome	Product created as an outcome that reflects expected impact of the project. (ex. level of technology improvement, economic outcome, employment effect, etc.)

[1] Reference: Ministry of Science and ICT (MSIT), 4th Edition of National R&D Standards Performance Indicators, 2014
[2] Reconstructed by H. Hong & J. Lee (2020)

Since many countries are interested in defining indicators for public R&D performance measurement, many studies were conducted to analyze relationships between indicators, mostly from input to output, yet there are not many studies covering outcome indicator. Economic outcomes – such as revenue, cost reduction, technology transfer, or import substitution – are crucial outcomes of public research projects which should be accounted in performance measurement system. Early empirical studies were interested in untangling the relationship between investment and performance. However, their findings were inconsistent, with some finding a positive relationship [111,112], whereas others found no signs of a relationship between the amount of investments and R&D performance [113]. Later studies became more focused on specific types of performance, such as publications or patents [28,114]. Auranen and Nieminen (2010) compared the relationship between funding and publication performance by using data from eight countries. Liu and Lu (2010) evaluated the performance of patents and publications of Taiwan research institutes by using data envelope analysis and network analysis. The interest in defining the relationship between inputs and innovation outputs also continued in studies for renewable energy R&D [17,115]. Costa-Campi et al. (2013) examined the factors that facilitate and hamper R&D innovation in energy firms in Spain. They found that R&D intensity is positively related to process innovation, whereas market factors (e.g., finance, size, and personnel) hinder the innovation. Plank and Doblinger (2018) conducted an empirical analysis on the effect of public R&D funding as a financial resource on firm-level R&D performance in the German renewable energy sector. They concluded that there exists a significant positive effect of public R&D funding in terms of absolute monetary value and past funding intensity on the number of patents. Nevertheless, the relationship between inputs and the performance of economic outcomes has not been studied extensively in the realm of renewable energy R&D.

Considering the idea from pioneers of the R&D performance measurement system, the proper R&D performance measurement system must be based on the evaluation of R&D outputs and outcomes rather than behaviors [107]. To become fully effective, the R&D performance measurement system must provide information that reduces the degree of uncertainty associated with the estimation of future revenues [116]. However, assessments on economic outcomes of R&D projects are much more complex than assessment on academic accomplishment. For that reason, there are not much of previous studies focusing on this research area. Despite of such difficulties, establishing research model for performance measurement system covering academic publication, patent registration, and economic outcome could provide empirical evidence to make assessment on economic outcomes gained from research projects.

Chapter 3. Analysis on the relationship between R&D team diversity and output in PRETDP with respect to demography and collaboration

3.1. Introduction

Diversity can often be a key to solving challenging problems; it can spark creativity through embracing various perspectives [117]. Energy transition and climate change are great challenges for humanity that require a great amount of creativity and innovative ideas. Although diversity has been a subject of studies for a long time, including R&D sector [118,119] and renewable energy [120,121], such efforts have not only limited to regional program and but also neglected experimental outputs – such as certifications or prototypes. Outputs are intermediate products that could affect overall R&D performance [107] so that analysis on the relationship between input and output in various perspective is significant.

This study is designed to determine, via analysis, if diversity in R&D consortium, in terms of collaboration researchers, has a meaningful relation to R&D performance of the public renewable energy sector in South Korea. From the panel data obtained from the National Science & Technology Information Service (NTIS), this study analyzed 430 public

R&D projects in the renewable energy. This study used intellectual performance (academic publication and patent) to analyze R&D team diversity by gender, age, educational background, and educational level, as well as homogeneous and heterogenous collaboration. This study found some meaningful results with respect to gender and age diversity on intellectual performance. In addition, a clear distinction was found between research activities for renewable energy and conventional energy sources (nuclear and thermal power) in terms of the workforce and its relation to performance. Some analysis results were not expected; however, this study tries to explain these results through discussion.

Analyzing the case of South Korea could be intriguing as its unprecedented economic growth during past decades has created less room for embracing social diversity in the work environment. South Korea had merely 70 USD per capita gross domestic product (GDP) in 1954 but achieved 26,900 USD in 2020, and it grew from being one of the poorest countries to being the 14^{th} in the world in terms economic status [122,123]. Its short-term success was largely due to its characteristics as a homogeneous society, meaning that the previous generation of South Korea had experienced the power of united decisions when they confronted struggles through difficult times and developed a pride for ethnic homogeneity [124,125]. However, circumstances are changing for South Korea, as its global status has improved. As more immigrants and new generations are flowing into the job market, people have different norms and expect to receive respect for their diversity. Such differences are creating concerns in the workplace, such as gender inequality [126], wider generation gap [127], and academic sectionalism [128].

As diversity in the workforce is becoming an important social criterion, this study could provide a new perspective on social dynamics in the renewable energy sector. The findings of this study could also inform policymakers regarding the relationship between diversity and R&D performance in public organizations engaged renewable energy R&D. This could be used as a managerial asset for public funding agencies. This paper is structured as follows: first, a literature review and hypothesis development on diversity is composed; then, a methodology section with data and variable descriptions is included, after which the results and discussion are based on statistical and econometric analysis, and finally, the conclusion is presented.

3.2. Demographic diversity

Diversity makes differences between individuals regarding any attribute that may lead to the perception that another person is different from the self [129]. In principle, diversity refers to an almost infinite number of dimensions, ranging from age to nationality, from religious background to functional background, from task skills to relational skills, or from political preference to sexual preference [130]. In practice, however, diversity research has mainly dealt with gender [119], age [131], race/ethnicity [132], educational background [133], and functional background [134]. R&D itself often deals with diversity since it has been found to be linked to creativity [135] and a positive impact on innovation [136]. Research teams with diverse backgrounds could bring together a wider spectrum of task-relevant knowledge, experience, and perspectives that are distinct and non-redundant [130]. Research on renewable energy often mandates diversity because problems such as energy transition and climate change require non-traditional thinking. Some previous studies related to clean energy and environment have dealt with diversity in various aspects such as technological diversity [137] and gender [138]. However, the diversity in renewable energy R&D has remained uncharacterized despite its contribution to energy innovation.

Despite its necessity, diversity is often described as a “two-edged sword” [66] or a mixed blessing [134] for its contradictory influence on organizational outcomes; consequently, it should be managed in the work environment [139,140]. This is especially true when diversity in the workforce is growing through several dimensions (e.g., age, gender, education). Diversity can positively influence work performance if it is managed properly. Multiple studies have shown that diversity can enhance performance by forming a new idea that leads to a positive cognitive effect [130,141]. In contrast, research activities may have no positive results if there are too many opinions and perspectives that cannot contribute to a solid idea. Some studies argue that diversity can reduce team performance by negatively affecting cohesion, decision-making quality, communication, and members’ commitment to the group [142,143]. This study hypothesizes that understanding the relationship between diversity and performance from several dimensions would assist those in the research environment to be better managed

3.2.1. Gender diversity

The gender structure of R&D personnel is closely related to the R&D performance. Studying relationship between gender structure and R&D performance not only can provide insights for policymakers to improve R&D performance but to achieve gender equality [144]. However, antithetic arguments exist in the literature. The research stream supporting gender diversity argues that differences in the brain structure between males and females [145,146] could influence the formation of perceptual views and solutions for problems [147,148]. Meanwhile, studies questioning the effect of gender diversity argues that the similarity of characteristics among group members contributes to promoting mutual attraction among members [149,150]; consequently, a group composed of diversified members would likely may experience high relationship conflict and internal tensions, which are unfavorable [144]. Antithetic arguments continue in empirical studies of R&D performance as well. Previous studies found that higher R&D performance favors high gender differences [151] or low gender differences [152], or no discernable gender difference [153]. None of these studies have focused on renewable energy R&D or economic outcomes of public R&D projects; therefore, this study needs to develop a hypothesis based on logical inference.

This study infers that having gender diversity would benefit both the intellectual and economic performance of research activities. In literature on the gender gap in renewable energy, a consistent argument is made that deliberate efforts to increase gender equity in the renewable energy sector could promise economic growth [11,138]. Generally, women have typical female traits such as friendliness and warmth, which promote socialization among R&D team members and motivate them to communicate and integrate their ideas while engaging in innovative activities [154]. Such traits would be beneficial for communication between team members as well as other divisions, such as marketing or manufacturing teams.

Hypothesis 1-a. Gender diversity has a positive relationship with the intellectual output of PRETDP

Hypothesis 1-b. Gender diversity has a positive relationship with the experimental output of PRETDP.

3.2.2. Age diversity

Age could explain changes in employees' work attitudes by affecting their needs, expectations, and values at a particular stage in life [131]. According to life span psychology and socioemotional selectivity theories, older workers exhibit better emotional control (Kanfer & Ackerman 2004), while the younger generation experience intense emotional reactions to negative stimuli and adversity at work [156]. From the perspective of social relationships, older workers are more oriented toward fulfilling social needs, while younger generations display greater motivation to meet their growth and career development needs [157,158]. Younger employees may be familiar with new technology and may have stronger academic skills [159], while the older generation may have more work experience, social skills, and comprehension of global issues [131]. Such differences created by age diversity may lead to synergy at work, leading to new insights or may create disharmony and reduce work performance.

However, considering that the R&D team is a small group, this study infers that age diversity might have more positive effects on performance. Regarding disharmony with age diversity, some believe that workplace diversity creates a number of problems in terms of communication, cooperation, and cohesion between employees, which might ultimately affect performance negatively (Carton & Cummings, 2012; Milliken & Martins, 1996). However, this inefficiency may refer to a large organization. The R&D team is a relatively small group, so diverse age groups could provide superior solutions to challenging problems and increase efficiency, effectiveness, and profitability [161,162].

Hypothesis 2-a. Age diversity has a positive relationship with the intellectual output of PRETDP

Hypothesis 2-b. Age diversity has a positive relationship with the experimental output of PRETDP

3.2.3. Diversity in educational background

To stimulate energy innovation, it is necessary to form a research team with different backgrounds and levels of education, as it is a complex task that requires new ideas [163]. Cohen & Levinthal (1990) found that absorptive capacity and problem-solving ability are likely to increase with a variety of knowledge structures based on their educational background. In addition, research teams with different educational levels can provide divergent ideas, novel approaches, and distinct alternatives [165].

In the context of performance, there are benefits and disadvantages of having educational background diversity; however, diversity could be very efficient in dealing with complex problems in renewable energy R&D. Some believe that educationally diverse teams are better prepared to solve complex problems because knowledge is available to them [166] and integrating different perspectives and opinions, encouraging inspiring discussion, and mutual learning could lead to creative solutions [167]. Although some view that education diversity is likely to increase the communication and coordination costs of integrating available knowledge or coordinating the innovation process [168,169], renewable energy R&D is an industry dealing with complex engineering problems, this study expects that the benefit of creative thinking would outweigh the communication cost on performance.

Hypothesis 3-a. Diversity in educational backgrounds has a positive relationship with the intellectual output of PRETDP

Hypothesis 3-b. Diversity in educational backgrounds has a positive relationship with the experimental output of PRETDP

3.2.4. Diversity in educational level

Diversity in educational level could be construed as a benefit or a threat to R&D performance; however, considering that deployment of renewable energy affects all social classes, diversity in educational level could act as a window to glance ideas of different social groups. Diversity in educational level could create preconditions for intergroup bias between in-groups and outgroups stemming from categorization processes [170], which could negatively influence team performance. However, examining the benefits, having an R&D team with different educational levels may provide divergent ideas, novel approaches, and distinct alternatives [165,171]. If the team has a more innovative team climate, which is conducive to innovative work on energy transition, team communication and educational level diversity could be strengthened [163]. Therefore, this study submits the hypothesis that diversity in education levels could positively affect both outputs

Hypothesis 4-a. Diversity in educational level has a positive relationship with the intellectual output of PRETDP

Hypothesis 4-b. Diversity in educational level has a positive relationship with the experimental output of PRETDP

3.3. Collaboration diversity

Research activities inherently call for collaboration between multiple researchers and organizations, because the information exchange reinforces discussion and the creation of new knowledge [172,173]. Lai and Chang (2010) asserted that utilization of external resources can increase competitiveness of an organization by complementing limited internal resources. The significance of inter-organizational collaboration has been emphasized in previous literature [47,174–178], and some of these previous studies were concentrated in empirical studies [173,179,180].

Their studies converge into a conclusion that functional differences between sciences and markets, and institutional separation between private and public control, needs of crosstabulation led to a creation of Triple helix of university-industry-government (UIG) relationship. There are several aspects in UIG relationship needed to be studied. A previous empirical study on UIG relationship have dealt with size and type of relationships [179], based on Schumpeter's idea on a positive relationship between firm size and innovation activity. Each entity has its own specific roles. Generally, universities have strength in fundamental researches and responsibility for leading academic research that could link to various innovations and increase in productivities [181]. Government Research Institutes (GRI) are functioned to absorb and accumulate knowledge created elsewhere and to generate new knowledge by conducting their own research and they diffuse that knowledge into the economy in a number of ways [182]. Especially, in developing countries, the role of GRIs is emphasized for concentrating on reducing technological differences against developed countries [183]. Because of such characteristics, GRIs are more likely to engage research activities in applicable and development stages. Industries are interested in product and/or process innovation [184], as well as development of academic research into actual product [181]. Because of those characteristics, collaborating with different entities or deciding which entities to lead the research collaboration could affect the performance of the project.

3.3.1. UIG Collaboration

UIG relationships have been the subject of many previous studies: conceptual studies [185], case studies [186,187], and empirical studies [179,180,188,189]. This dynamic interaction model of UIG is called the Triple Helix, which is a theory referenced frequently for measuring innovation in a knowledge-based economy [190]. They have all pointed out that forming collaborations through the UIG relationship is important for enhancement of

R&D performance; however, they have not addressed the behavioral difference in types of collaboration to explain the difference in the performance of output and outcome.

Although the entire purpose of R&D collaboration is sharing resources, the purposes of collaboration in for-profit and non-profit organizations are different. Collaboration between for-profit organizations is motivated mainly by cost economization [191]. In this type of collaboration, companies seek to lower the cost of their R&D activities through sharing them with other companies. On the other hand, collaboration between non-profit organizations arises mainly from the need to resolve complex problems [192]. Many non-profit organizations are staffed by professional workers who are highly attached to their own professions and their flat hierarchy [193], which is a good environment for sparking innovation but would cause problems in controlling human resources within the increase in economies of scale. So, when a project requires increases in the scale of economies and the complexity of goals, collaboration involving both profit and non-profit organizations is demanded. In our study, we have grouped the sub-categories of the UIG relationship together in a way that they can be anticipated to have similar relationships as regards each output.

Most of the previous literature covers part of the sub-categorized UIG relationship. There is a study concluded that the size of collaborations and the amount of government investment had an impact on forming the UI relationship [179]. Another study found that types of leaders can contribute to the academic and patent performance of industrial R&D programs in South Korea [194]. However, previous studies have not examined how each type of collaboration and leader can contribute to the innovation outputs and outcomes of public R&D performance, and especially not in the cases of renewable energy R&D programs. It is important to understand how university, industry, and government function both individually and collaboratively in the context of UIG relations.

Because the renewable energy industry has insubstantial industrial base comparing to centralized power supply industry, the government of South Korea has been promoting UIG-based collaboration in photovoltaics, wind power, and fuel cell. In 2008, *The Third Basic Plan for Renewable Energy Technology Development and Supply* was announced to cultivate cooperation between UIG to secure original technologies and human resources in renewable energy industry. *The Fourth Renewable Energy Basic Plan*, which published in 2014, had also emphasized the establishment of the UIG cluster for equipment test and assessment for renewable energy sources. Such inclination had also been reflected on public renewable energy R&D.

3.3.2. Homogeneous and heterogeneous collaboration

Heterogeneity in R&D collaboration was studied as a strategic tactics of research teams to share knowledge and access new knowledge [195]. In previous research, many types of R&D collaborations were considered. Some studies focused on cooperative and non-cooperative research [194,196]. Some of major stream research were dealing with patterns of collaborations, such as UIG relationship [197] or value chain (e.g., competitor, supplier, and customer) had been attempted [198]. There were studies concentrated on cooperative structures, company size, or affiliated district [199,200]

Many studies view that heterogeneous collaboration would provide a benefit to engaged organizations [201,202]. Berchicci (2011) suggests that organization engaged with a greater number of heterogeneous types of partners could have more benefits in innovative output. Another study conducted by Franco and Gussoni (2014) provided evidence that public subsidies positively affect inclination of an organization to engage in heterogeneous cooperation in several countries, especially for organizations in the service sector. This means that heterogeneous collaboration for R&D activities conceived as a beneficial strategy for firm to gain competitive advantage both in government fund and in knowledge.

Hypothesis 5-a. Heterogeneous collaboration would have more positive relationship with the intellectual output of PRETDP than homogeneous collaboration

Hypothesis 5-b. Heterogeneous collaboration would have more positive relationship with the experimental output of PRETDP than homogeneous collaboration

3.4. Methodology

3.4.1. Data set

This study uses panel data obtained from the National Science &Technology Information Service (NTIS), originated from the "Energy R&D Result Analysis Reports" issued by the Korea Institute of Energy Technology Evaluation and Planning (KETEP). These are annual reports issued from 2011 to 2020 based on surveys collected from researchers who participated in public energy research projects. The survey population included public energy R&D projects completed within five years from the year of the survey. Thus, there are overlaps in the population; later surveys contain more updated information on the same project. The response rate to this survey is above 99%. More than 10,000 responses were collected from 2016 to 2020. To avoid counting the same projects, this study selected the latest year of the survey. Consequently, we selected 430 projects completed between 2012 and completed 2016. These data contained various information items, such as type of organization, type of project, sector, period, investigation year, investment in finance and kind, collaborators, number of participations, keywords, evaluation results, and outcomes.

3.4.2. Research model and variables

3.4.2.1. Dependent variables

This study developed a research model to identify the relationship between input of R&D projects and two types of output dependent variables: *intellectual output* and *experimental output*. *Intellectual output* is constructed using the weighted sum of intellectual outcomes, including the number of patents and research papers. To measure performance in R&D projects, both academic publications [203,204] and patents [205] are widely used as indicators in quantitative approaches. In public R&D, number of academic publications are often used as quantitative performance indicators for the purpose of comparison between different public R&D programs [203,204,206]. Patents have been known as a representative proxy to measure the innovativeness of an organization [205], and many previous studies have adopted a number of patents as one of the intellectual output [207–209]. Therefore, it is rational to represent intellectual output with the combination of the performance of patents and research papers. To validate intellectual output, the survey institution verifies DOI and acknowledgement phrases for academic publication and patent numbers through the Korea Institute of Patent Information (KIPI), which is a national institution for managing patent registration. *Experimental output* indicates intermediate products created by actions of lab test and development. This study used certification and prototype to actualize experimental output. Certification is an official acknowledgement, provided with document, showing developed product in a project has met certain technical standard or protocol to be allowed for business use [210]. Prototype is an intermediate product of item actualization of research activities, which often requires certification for proof. For validation process, prototype must be reported with the picture with acknowledgement label on the product within research report for PRETDP. Certification must be enlisted in government standard portal (standard.go.kr) to show that authority institution has been approved by the government.

3.4.2.2. Independent variables

Demographic Diversity. Previous studies defined demographic diversity as the distribution of differences among research team members of the firm with respect to a common attribute (Harrison & Klein, 2007) and used the index of diversity proposed by Blau (1977) to calculate categorical diversity attributes [133], as shown in equation below:

$$Demographic\ Diversity = 1 - \sum_{i=1}^{k} p_i^2$$

where k indicates the total number of categories of a variable, and p_i is the proportion of research team members who belong in category k. Therefore, for instance, gender diversity only has two categories (male and female) so that Blau's diversity index for gender could range from 0 (where an R&D team is composed of a single gender) to 0.5 (where a team has a balanced number of both males and females). For age diversity, this study followed the categorization proposed by Wegge et al. (2008), where categorization was made by age cohort: 1) ≤ 30 years old, 2) 31–40 years, 3) 41–50 years, 4) 51–60 years, and 5) ≥ 61 years. The age cohort was calculated from the starting year of the project to avoid bias. Therefore, age diversity could be varied from 0 (where only one age cohort exists in an R&D team) to 0.8 (where a balanced age cohort exists in an R&D team). For the categorization of educational background diversity, this study referred to the study by Schubert and Tavassoli (2020) with a small variation: 1) engineering and technology; 2) natural science; 3) liberal arts; 4) general education (no major); and 5) other majors (e.g., medical, pharmaceutical, art, and physical education). Blau's heterogeneity index could vary from 0 (when all R&D team members belong to the same educational background category) to 0.75 (when there are equal numbers of R&D team members across all educational backgrounds). Other majors could not specify further because of the small sample size. The categorization of educational level diversity was mostly referred to from the study of Garcia Martinez et al. (2017) and Valls et al. (2016), but this study made a modification by adding 'master' group because the renewable energy R&D sector in South Korea largely relies on researchers with an advanced degree. Therefore, educational diversity is composed of four categories: 1) Ph.D., 2) master, 3) bachelor's degree, and 4) secondary education. Blau's heterogeneity index could vary from 0 (when all R&D team members fall within the same educational level) to 0.75 (when there are equal numbers of R&D team members across all educational levels).

Collaboration Diversity. The dynamic interaction model of University-Industry-Government Research Institutes (UIG) relationship is originated from the Triple Helix model, which is a theory referenced frequently for measuring innovation in a knowledge-based economy [190]. UIG relationships are composed of multiple combinations from *university (U), industry (I). and government research institutes (G).* This study re-categorized these combinations by behavioral characteristics of consortium [2]: *homogeneous collaboration, heterogeneous collaboration,* and *non-collaboration*. *Homogeneous collaboration* indicates form of consortium with same motivation; this study used *for-profit* and *non-profit*. *For-profit* contains the combination with enterprises only *(I) to (I)*. This is a collaboration type motivated mainly by cost economization, where companies seek to lower the cost of their R&D activities through sharing it with other companies [191]. *Non-profit* contains combinations with university and government research institute, which indicates *(U) to (U), (U) to (G),* and *(G) to (G).* The collaboration between non-profit organizations arises mainly from the need to resolve complex problems [192]. Many non-profit organizations are staffed by professional workers who are highly attached to their own professions and their flat hierarchy [193], which is a good environment for sparking innovation but could cause problems in controlling human resources within the context of an increase in economies of scale. *Heterogeneous collaboration* is a type of consortium form with different motivation; this could be specified into *bilateral* and *trilateral* collaboration in the context of UIG relationship. *Bilateral* contains one entity from *non-profit* and another from *profit*, which indicate *(I) to (U)* and *(I) to (G)*. *Trilateral* contains all three entities of UIG relationship. *Bilateral* and *Trilateral* type of collaboration is in demand when a project requires increases both in the scale of economies and the complexity of goals, which are also most common type of consortium in PRETDP.

3.4.2.3. Control variables

R&D Team Control This study controlled few factors related to research consortium and researchers in consortium. *Consortium size (log)* indicated logarithm value of number of participant organizations in the group, as previous literature pointed out necessity of logarithm conversion to compensate skewness [214]. *Participants from industry* is also controlled since PRETDP is exceptionally dependable on experimental development stage projects with lots of organizations participated from the industry sector. This study controlled this variable by calculating ratio of participant organizations from the industry sector divided by the consortium size of each project. *Leader's Experience in PRETDP* was calculated by counting whether leader organization had previously involved in PRETDP as either leader or participant organization; this variable was considered as previous study pointed out how capacity of leader organization can have massive impact on project outcome [215]. *Number of researcher (log)* indicates total number of research participants in a project, which is also used logarithm scale to compensate skewness.

R&D Project Control This study also controlled several factors relate to project characteristics. *Government investment (log)* and *private investment (log)* had to be included since they are fundamental input of public research projects. *Private investment* is composed of not only cash but also in-kind, which is calculated by the number of equipment, facilities, or non-paid researchers[3]. *Project duration* is also controlled since the length of the time span for project participants working together found to have an influence on project's performance [214,216,217]. *Technology Readiness Level* is a type of measurement system used to assess the maturity level of a particular technology with level of scale 1 to 9, initially used by NASA but often used in energy field as well [218]. This metrics could show how much technology has been improved from the initiation. Normally, although definition might slightly vary from institution to institution, Technology Readiness Level (TRL) with 1 to 3 indicates research at basic research stage, 4 to 6 for research at applicable research stage, and 7 to 9 for research with commercial or demonstration purpose. This study used TRL at the project completion stage which has been reported by principal investigators and confirmed at project selection committee.

[3] *Operation Guidelines for Projects for Innovation of Industrial Technology* states that payroll of researchers receiving salary from their institutions must be calculated in-kind to prevent duplication in payment.

3.4.2.4. Hierarchical regression model

This study constructed two regression equations with the variables introduced in earlier sections. A hierarchical regression model was employed for both equations. As this model is found to be effective in identifying the moderating effect without loss of information, it has been used to study renewable energy [219,220]. This model works well, especially if the moderating and independent variables are forms of continuous variables (Cohen et al., 2013; MacKinnon, 2000). Also, when the number of interaction terms is more than one, it is better to input all terms together [223,224], avoiding the increase of type 1 errors [221]. The statistically significant level is designated as $|p| \leq 0.1$.This study uses the *Network X* package in Python to calculate the degrees of keyword network and SPSS for the hierarchical regression analysis as Equation below.

$$\begin{aligned} output_{intl,exp} = \ & \alpha + \beta_{gender}X_{gender} + \beta_{age}X_{age} + \beta_{edu.background}X_{edu.background} \\ & + \beta_{edu.level}X_{edu.level} + \beta_{homogeneous.col}X_{homogeneous.col} \\ & + \beta_{heteorogeneous.col}X_{heterogeneous.col} + \beta_{con.size}X_{con.size} \\ & + \beta_{part.ind}X_{part.ind} + \beta_{num.res}X_{num.res} + \beta_{gov.inv}X_{gov.inv} \\ & + \beta_{prv.inv}X_{prv.inv} + \beta_{prjt.dur}X_{prjt.dur} + \beta_{TRL}X_{TRL} \end{aligned}$$

Table 4. Variable statistics for study on R&D Team diversity

Variables		**Descriptions**	**Reference**	**Obs.**	**Min**	**Max**	**Mean**	**Std.**
Dependent Variable	Intellectual Output (log)	Log scale on sum of patents and academic publications	[144,225–227];	430	0.00	1.88	0.81	0.45
	Experimental Output (log)	Log scale on sum of certifications and prototypes		430	0.00	1.51	0.36	0.36
Diversity in R&D Team - Demography	Gender	1) Male or 2) Female	[119,144,228,229]	430	0.00	0.50	0.23	0.13
	Age	1) ≤ 30 years old, 2) 31–40 years, 3) 41–50 years, 4) 51–60 years, or 5) ≥ 61 years	[131,228,230]	430	0.17	0.80	0.58	0.11
	Educational Background	1) engineering and technology, 2) natural science, 3) liberal arts, 4) general education, or 5) others	[133,163,230]	430	0.00	0.73	0.30	0.19
	Educational Level	1) Ph.D., 2) master, 3) bachelor's degree, or 4) secondary education	[227–230]	430	0.00	0.75	0.59	0.12
Diversity in R&D Team - Collaboration	Homogeneous Collaboration	1) for-profit collaboration : Industry to Industry combination 2) non-profit collaboration: university or GRI included combination		430	0.00	1.00	0.20	0.39
	Heterogeneous Collaboration	1) Bi-lateral collaboration: Industry to University or Industry to GRI 2) Tri-lateral collaboration: UIG all included		430	0.00	1.00	0.67	0.47
	Non-Collaboration	Single Entity projects (industry, university, or GRI)		430	0.00	1.00	0.14	0.34
Control Variables - R&D Team	Consortium size (log)	Log scale on number of participant organizations	[131,163,227]	430	0.00	1.15	0.43	0.27
	Participants from Industry	ratio of participant organizations from the industry sector divided by the consortium size	[214]	430	0.00	1.00	0.43	0.30
	Leader's experience in RE R&D	leader organization's previous experience in public renewable energy R&D program	[231]	430	0.00	18.00	3.28	2.37
	Number of Researcher (log)	Log scale on number of researchers	[119]	430	0.48	2.43	1.41	0.35
Control Variables - R&D project	Government investment (log)	Log scale on monetary public investment	[228,229]	430	0.14	2.45	1.20	0.37
	Private investment (log)	Log scale on monetary + in-kind (equipment, personnel) private investment	[228,232]	430	0.00	2.49	0.71	0.55
	Project duration	project periods in year	[163]	430	1.00	9.00	3.67	0.74
	Technology Readiness Level	Indicating maturity level of a particular technology (scale from 1 to 9) at project completion	[144,227]	430	2.00	9.0	4.99	1.75

3.5. Results

3.5.1. Dataset analysis

This study uses 430 national R&D projects in the renewable energy sector. The detailed statistical description is shown in **Table 4**. The data transformation technique is used on continuous variables – *government investment*, *private investment*, *consortium size, intellectual output,* and *experimental output* – to compensate for its high dispersion, considering their value of skewness, kurtosis, and the difference between standard deviation and mean. The log transformation is used on these variables to prevent the distortion of the statistical relationship. The Pearson Correlation test has been conducted and provided in appendix table. Variance Inflation Factor (VIF) is also investigated to check multicollinearity; all value has been found to be less than 10.

3.5.2. Econometric analysis result on R&D output

Intellectual output This study constructed seven models to observe the change in adjusted R-squared value, as shown in **Table 5**. All model has been constructed for 430 projects in PRETDP. Model 1 is estimated with R&D project control variable only. Model 2 is estimated with the addition of R&D team control variables from Model 1, which is used as basis model for comparison with rest of model. Model 3 has added collaboration diversity variable on Model 2. Model 4 to 6 are diversity specific model, each concentrating on age, educational background, and educational level to have detailed analysis. Model 7 is the complete model for R&D team diversity. To meet the condition of hierarchy regression model, the adjusted R-squared value must need to be improved or at least equal within the addition of variables. From this perspective, Model 1 → Model 2 showed increase in R-squared value; Model 2 → Model 3 was identical; Model 2 → Model 4 and 5 showed increase, but Model 2 → Model 6 was decreased, meaning that findings from this model may not be referrable. Model 2 → Model 7 showed increase in R-squared value in great deal so that this model could be referred for moderating analysis with moderating variable. For the interpretation of coefficients, this study used p-value, known as the confidence interval, with the range from 90% to 100% interval. This study used above 99%, 99%, 95%, and 90% range for the interval range. Using this interval range with the sign of coefficients, this study analyzed the hypothesis. Detailed discussion and confirmation on hypothesis are provided in discussion sector.

Experimental output This study constructed seven models to observe the change in adjusted R-squared value, as shown in Table 6 and Table 5. All model has been constructed for 430 projects in PRETDP. The structure of model is same as previous analysis. Model 1 is estimated with R&D project control variable only. Model 2 is estimated with the addition of R&D team control variables from Model 1, which is also used as basis model for comparison with rest of model. Model 3 has added collaboration diversity variable on Model 2. Model 4 to 6 are diversity specific model, each concentrating on age, educational background, and educational level to have detailed analysis. Model 7 is the complete model for R&D team diversity. For the confirmation of hierarchy regression model, the adjusted R-squared value was also compared, and similar pattern was found. Model 1 → Model 2 showed increase in R-squared value; Model 2 → Model 3 was identical; Model 2 → Model 4 and 5 showed increase, but Model 2 → Model 6 was decreased, meaning this model is also not referrable. Model 2 → Model 7 showed slight increase in R-squared value, meaning this model could be suitable for moderating analysis on next section. This study used p-value with above 99%, 99%, 95%, and 90% range for the interval range. Using this interval range with the sign of coefficients, this study analyzed the hypothesis. Detailed discussion and confirmation on hypothesis are provided in discussion sector.

Table 5. Analysis result of R&D team diversity on intellectual output

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Diversity in R&D team – Demography							
Gender							0.518***
Age				-0.821***			-1.008***
≤30				-0.002			
31~40				-0.001			
41~50				-0.007			
51~60				-0.022*			
≥61 (baseline)							
Education background					-0.026		-0.043
Eng. & Tech.					0.000		
Natural Science					0.016***		
Liberal Arts					-0.032**		
General education					-0.001		
Other majors (baseline)							
Education level						-0.017	0.162
Ph.D.						0.003	
Master						0.001	
Bachelor						-0.001	
Secondary (baseline)							
Diversity in R&D team – Collaboration							
Homogeneous collaboration							0.001
For-profit			0.004				
Non-profit			-0.016				
Heterogeneous collaboration							-0.044
Bilateral (UI or IG)			-0.106†				
Trilateral (UIG)			-0.105				
Non-collaboration (baseline)							
Control – R&D Team							
Consortium size (log)		0.284**	0.281**	0.211**	0.266**	0.278**	0.209**
Participants from industry		-0.263**	-0.278**	-0.188*	-0.192*	-0.243**	-0.131
Leader's experience in RE R&D		0.008	0.009	0.010	0.005	0.006	0.009
Number of researchers (log)		0.544***	0.551***	0.466***	0.504***	0.538***	0.380***
Control – R&D Project							
Government investment (log)	1.031***	0.364**	0.326**	0.457***	0.338**	0.359**	0.439***
Private investment (log)	0.450***	-0.262***	-0.197**	-0.158**	-0.237***	-0.276***	-0.130†
Project duration	-0.051†	-0.059*	-0.058*	-0.076*	-0.035	-0.054*	-0.076**
Technical Readiness Level	-0.009	-0.005	-0.001	0.001	-0.003	-0.004	-0.002
Adjusted R-squared value	0.286	0.383	0.383	0.441	0.430	0.380	0.451

*** (Note) : *** p ≤ 0.00; ** 0.00 < p ≤ 0.01; * 0.01 < p ≤ 0.05; † 0.05 < p ≤ 0.1**

Table 6. Analysis result of R&D team diversity on experimental output

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Diversity in R&D team – Demography							
Gender							-0.211†
Age				-0.117			-0.259†
≤30				-0.000			
31~40				-0.004			
41~50				-0.005			
51~60				-0.002			
≥61 (baseline)							
Education background					0.010		-0.089
Eng. & Tech.					0.001		
Natural Science					0.000		
Liberal Arts					-0.011		
General education					-0.003		
Other majors (baseline)							
Education level						-0.089	-0.042
Ph.D.						0.003	
Master						0.000	
Bachelor						0.000	
Secondary (baseline)							
Diversity in R&D team – Collaboration							
Homogeneous collaboration							0.049
For-profit			0.210*				
Non-profit			-0.038				
Heterogeneous collaboration							0.106†
Bilateral (UI or IG)			0.090†				
Trilateral (UIG)			0.092				
Non-collaboration (baseline)							
Control – R&D Team							
Consortium size (log)		-0.004	0.000	-0.018	0.002	-0.005	-0.002
Participants from industry		0.358***	0.300***	0.359***	0.370***	0.361***	0.369
Leader's experience in RE R&D		0.030***	0.030**	0.029**	0.031**	0.030**	0.031***
Number of researchers (log)		-0.001	-0.016	-0.039	-0.017	-0.008	-0.026
Control – R&D Project							
Government investment (log)	0.107	0.176†	0.214*	0.171†	0.172†	0.165†	0.192†
Private investment (log)	0.244***	0.044	-0.015	0.047	0.035	0.038	0.011
Project duration	-0.065**	-0.048*	-0.044†	-0.045†	-0.049*	-0.045	-0.051
Technical Readiness Level	0.034***	0.021*	0.016†	0.022*	0.024*	0.022	0.020
Adjusted R-squared value	0.264	0.324	0.324	0.324	0.325	0.319	0.328

(Note) : *** p ≤ 0.00; ** 0.00 < p ≤ 0.01; * 0.01 < p ≤ 0.05; † 0.05 < p ≤ 0.1

3.6. Discussion

Table 7. Estimation summary of R&D team diversity and intellectual output

Variables	Intellectual Output	Experimental Output	Direction of significant coefficients
	Confidence Interval of Estimated Coefficient (P-value) (%)		
R&D team Diversity – Demography			
Gender			Different
Age			Identical
≤30	Not Significant	Not Significant	
31~40	Not Significant	Not Significant	
41~50	Not Significant	Not Significant	Identical
51~60			
≥61 (baseline)	-	-	
Education background	Not Significant	Not Significant	
Eng. & Tech.	Not Significant	Not Significant	
Natural Science		Not Significant	Different
Liberal Arts		Not Significant	Different
General education	Not Significant	Not Significant	
Other majors (baseline)	-	-	
Education level	Not Significant	Not Significant	
Ph.D.	Not Significant	Not Significant	
Master	Not Significant	Not Significant	
Bachelor	Not Significant	Not Significant	
Secondary (baseline)	-	-	
R&D team – Collaboration			
Homogeneous collaboration	Not Significant	Not Significant	
For-profit	Not Significant		Different
Non-profit	Not Significant	Not Significant	
Heterogeneous collaboration	Not Significant		Different
Bilateral (UI or IG)			Different
Trilateral (UIG)	Not Significant	Not Significant	
Non-collaboration (baseline)	-	-	
Control – R&D Team			
Consortium size (log)		Not Significant	Different
Participants from industry	Not Significant		Different
Leader's experience in RE R&D	Not Significant		Different
Number of researchers (log)		Not Significant	Different
Control – R&D Project			
Government investment (log)			Identical
Private investment (log)		Not Significant	Different
Project duration			Identical
Technical Readiness Level	Not Significant		Different

∗ (Note) Confidence Interval (positive) = 90%; = 95%; = 99%; = above 99%
Confidence Interval (negative) = 90%; = 95%; = 99%; = above 99%

Discussion on identical factors Discussion points are those variables had identical ‘direction of significant coefficients’ in Table 7. *Age diversity* is shown to have negative effect on both intellectual and experimental output, although confidence level was little different. This is understandable since this finding is consistent with findings from previous studies [228,233]. More specifically, age group of 41-50 has shown to be less effective than age group of 61 or more. This study infers that such ineffectiveness has been caused by wide age gaps in South Korean society, which has also pointed out in study of Han (2015). Age gaps in South Korean society may have been accelerated by rapid industrialization of the country, which raised communication cost between age groups [127], especially those born in late 1970s may have exposed more to this sudden changes of economic environment.

Project duration is another common factor shows negative relationship to both R&D outputs. Based on managerial work experience in PRETDP, this seems to be related to the problem of project period extension. Normally, mid-to-long term projects in PRETDP has three to five years of project terms; but occasionally, this period can be extended from few months to few years when problem like financial deterioration of participating firms or delay in certification approval. This means that even when those projects clear up whatever problems they have, their status of intellectual and experimental outputs are not as good as most of projects completed without project period extension.

Discussion on different factors   Discussion points are those variables had different 'direction of significant coefficients' in Table 7. *Gender diversity* showed positive relationship with intellectual, while it has negative relationship with experimental output. This study found the reasonable explanation for such behavior in previous study [144]. Kou et al (2020) study showed that demographic proportion of female researchers are found to have relationship with more of academic output, while males' proportion are more related to experimental works. This could be another evidence to biological and social difference in role of male and female that have influence on research team climate following previous works on gender diversity [145,146,148].

Education background diversity seems not to have significancy in diversity index, however, it seems necessary to think about why natural science shown positive relationship to intellectual output when liberal arts showed negative one. R&D activities in renewable energy is highly depend on workers in Science, Technology, Engineering, and Mathematics (STEM) [234]. This study shown that small diversity inside the boundary of STEM is beneficial to knowledge increase, while too much difference in line of knowledge stream outweighs the benefit of diversity and end up causing increase in communication and coordination cost [168,169].

Homogeneous and *heterogenous collaboration* also showed some differences in estimation results. The fact that heterogeneous collaboration showing insignificancy – even negative for bilateral subgroup – was inconsistent with findings from previous study [231]. This study infer that such difference occurs because the focal institution of PRETEDP is industry. This argument makes more sense when it compares to the positive relationship of heterogenous relationship on experimental output; showing for-profit and bilateral relationship has more positive relationship indicates that the involvement of industry is essential for experimental output. Experimental outputs are product of R&D activities more close to business purpose, so in this way, this findings might be aligned with previous studies showing positive relationship between heterogeneous collaboration and commercialization [180,235]

Control Variables showed some differences in estimation results. Consortium size and log value of number of researchers showed positive relationship with intellectual output. This means that more researchers should be involved to create more intellectual output, but this is not effective for experimental output. Meanwhile, participants from industry and previous experience of leaders on PRETDP could be helpful for creating more experimental output. Therefore, resource requirements for more performance are quite different for outputs.

Also, for intellectual output, private investment was not necessary as its output does not depending on industrial participants. For experimental output, Technical Readiness Level at project completion stage was important since commercialization may have been their sole purpose.

Based on the analysis on the direction of significant coefficients, the result on the analysis of hypothesis has been summarized as in Table 8. Only hypothesis on gender and age has been confirmed, while others are rejected due to lack of significancy in coefficients.

Table 8. Summary of hypothesis test for intellectual output

Hypothesis	**Result**
For intellectual output	
H1-a. gender diversity	**Positive**
H2-a. age diversity	**Negative**
For experimental output	
H1-b. gender diversity	**Negative**
H2-b. age diversity	**Negative**
H5-b. heterogeneous collaboration	**Positive**

* (Note) rest of hypothesis in H5 and H6 found to be not significant

3.7. Conclusion

Knowing how R&D team diversity interacts with the output performance of PRETDP could reduce uncertainties of R&D managerial practices. Although there was a time that these uncertainties were thought to be uncontrollable, the perspective on public R&D has changed and now demanding more effective management. Renewable energy R&D is experiencing a global increase in public expenditure. Nevertheless, this is troubling due to unfledged market conditions and social issues such as climate change. Making investigation on the performance of PRETDP could provide some insights to improve its managerial system, which will eventually have spillover effect on better renewable energy technology deployment.

This paper assessed PRETDP in South Korea by focusing on R&D team diversity and output. R&D team diversity was separated by demographic diversity and collaboration diversity. This study analyzed 430 projects in South Korea's national renewable energy R&D program completed between 2009 and 2015. This study found that there is similarity between intellectual and experimental output in terms of R&D team diversity. *Age diversity* is negatively related with both outputs, showing that age gaps in South Korean society is still creating disadvantage in communication cost. On the other hand, there were many differences. *Gender diversity* showed positive relationship with intellectual, while it has negative relationship with experimental output. Inferring from findings from previous study, demographic proportion of female researchers is positive for creating academic output, while males' proportion is more related to experimental works. *Education background diversity* seems not to have significancy in diversity index, however, intellectual output was more positively affected by natural science and negative affected by liberal arts. It means that study shown that small diversity inside the boundary of STEM is beneficial to knowledge increase, while too much difference in line of knowledge stream outweighs the benefit of diversity and end up causing increase in communication and coordination cost. For *heterogeneous collaboration*, this study found that commercialization-driven research focus of PRETDP makes heterogeneous collaboration with experimental output to be more positive.

This study showed that demographic diversity of R&D teams in PRETDP not only have impacts on performance at both directions, but also works differently depending on types of outputs. Gender balanced projects functions better with academic works, but not with projects aiming for creating more experimental works. Age diversity in PRETDP is affected by large gender gap in South Korean society so that it would not foster desirable research environment for more outputs. Diversity in educational background and inclusion of more advanced degree workers are crucial factors for intellectual output while it was not for experimental works. Knowing such tendency would help managers to understand how diversity works with the output performance of PRETDP.

Diversity of collaboration of R&D teams in PRETDP also showed impacts on performance of all projects' group. So, in general, research consortium in PRETDP seeks for skill sharing among member organizations of research consortium by forming heterogenous collaboration. PRETDP's major focus is commercialization, therefore, these consortiums tend to include enterprise; however, having negative relationship with private investment suggests that skill sharing motivations are accelerated by more inclusion of non-profit research organizations.

The findings of this study highlight the relationship between diversity and R&D performance, which could be used in the public R&D managerial sector. As diversity in the workforce is becoming an important social criterion, renewable energy R&D should find a way to embrace it and manage it in a way that enhances R&D performance. By providing information to policymakers, this study could contribute to the improvement of the public renewable energy R&D managerial system in South Korea.

Chapter 4. Analysis on the relationship between output diversity and outcome in PRETDP: focusing on output quantity and quality

4.1. Introduction

There are many public research R&D programs that need to be studied for economic outcomes, and public R&D renewable energy programs are among the most neglected areas for empirical study since many governments radically increase their expenditures on renewable energy R&D in order to keep up with global trends of energy transition and to withstand climate change [236–238]. The economic outcomes of renewable energy R&D are a critical component of renewable energy R&D evaluation, as improvement in economic outcomes indicates the utility and potential of projects for the expansion of renewable energy generation and capacity.

Especially, many of previous studies are concentrating on input to output relationship [15,17], and miss out discussion on the relationship between output and outcome. Outputs are intermediate products of a research project that could act as check points for showing whether research activities of a project are heading right direction or will meet its objective.

Considering limited resources are available in public sector, studying the relationship between output and outcome could reduce the risk of uncertainty and enhance performance that could also benefit indirectly through social development or economic growth [239].

The main purpose of this study is to find relationships between R&D output and outcome in Public Renewable Energy Technology Development Program (PRETDP). Two types of output are applied in this study: intellectual and experimental. Intellectual outputs are sum of academic publication and patents, whereas experimental outputs are composed of certifications and prototypes. Both outputs are considered in quantity and quality. For outcome, also two variables are concerned: commercialization and employment effect. Commercialization means whether project had created economic outcome such as sales, cost reduction, technical transfer, and import-substituting effect. Employment effect is number of people hired for processing or maintaining business related to commercialized outcome of a project. This research analyzed 430 projects that participated in PRETDP, which has initiated project in 2009 and completed by 2015. South Korea is one of the Mission Innovation member countries, pledging to double its R&D investment by 2021 and set an ambitious goal of 20% of electricity generation from renewable energy sources by 2030 [240]. Although South Korea is committed to improving the effectiveness of public renewable energy R&D

investment, it is marked by low levels of outputs as opposed to a high level of R&D intensity [3]. The public renewable energy R&D program has been criticized for a low R&D commercialization rate compared to other public R&D programs in South Korea [19]. Analyzing South Korea's case could provide lessons for other countries suffering from low performance in public renewable energy R&D. This paper is structured as follows: first, review on the literature of R&D output management with hypotheses development. Then, data source and methodology are elaborated, as well as variable descriptions and econometrical analysis. Finally, discussions and conclusions are attached.

4.2. Strategic management of public R&D output

Based on first generation measurement system proposed by Brown and Svenson (1988) shown in introduction section, I have demonstrated how R&D system can be categorized into input, processing system, output, receiving system, and outcome. Among those parts from R&D system, outputs are intermediate products that could be created by pure research activities, which could act as check points for assessing whether research activities of a project are going on right direction or will meet its objective. The boundary of outputs may vary from subjective to subjective, but typically contains patents, new products, new processes, publications, or simply facts, principles, or knowledge that were unknown before [107]. So, for example, if project has published a journal article, designed a prototype, or won an award, they should be counted as intermediate products of research projects. These outputs are easy to be measured and quantified for comparison between projects for efficiency. Also, it is more dependable than simply checking on research behaviors or activities. Output is an important part of R&D performance measurement system as Brown and Svenson suggested, and the performance measurement system can be better functioned when both quantity and quality of output are accounted.

4.2.1. Importance of output in public R&D

In public research projects, outputs are more bounded by measurable intermediate products. At the time of applying for project call, research applicants must submit a document with quantified numbers of targeted output quality and quantity. Desired output may vary from public R&D program to program, however, there are certain criteria to be reported in PRETDP. Typically, quantity and quality of academic publications and patents are accounted for most of projects as intellectual outputs. If the project is more involved in applied research stage, prototypes or certification may require for proving their accomplishments. If project is involving demonstration, procedures requiring for commercialization may be asked to be turned in, such as Memorandum of Understanding or detailed inspection report from relative authority.

The completion of projects in PRETDP often takes three years or more. If it is designed for long term project, could be up to five years; very few projects take a decade for completion. Therefore, expecting output from those projects are quite large and unwieldy to manage without proper system. This is not just for PRETDP alone, but could be observed in other industries in defense or airflight development [241]. Therefore, if R&D program manager does not know the relationship between output and outcome in his or her managing projects, it becomes difficult to fathom whether their projects are moving toward right direction; or they might ask for researchers to fulfill unnecessary outputs that has no relevancy to outcome accomplishment.

4.2.2. Output diversity

In fact, it was difficult to find previous studies that perfectly matches with the aim of this study because output management in public R&D sector has not been practiced until few years ago. Especially, in South Korea, only considerable outputs were academic publications and patents; other types of output such as prototype, certification, field test, or standardization commitment was not properly surveyed nor collected in National Technology Information Service for performance measurement purpose.

Nevertheless, there were some referrable previous studies in the stream of patent portfolio management or product diversity in private sector [37–39,242]. Although their variables are different from output variables in public R&D domain, they have similarity in terms of intermediate product made from input resources and studying how those intermediate products relates to firm performance. Altaf and Shaw (2015) studied how different number of product lines affect internationalization and firm performance. Sukpanich and Rugman (2007) studied how proportion of sales attributed to business segment affect the return on sales of firms, similar scope of variables was also studied Tallman and Li (1996).

Findings in those studies are converging to the notion that excessive product diversity could negatively influence the firm performance. This is because private firms are seeking for single outcome, which is increase in sales, meaning that similar result might not be obtainable in public R&D studies. Public R&D is seeking for business value, as well as policy alignment. However, one can agree with the notion that management in intermediate output is important for research project, which requires constant attention from research community.

Hypothesis 1-a. Output diversity has a positive relationship with the projects' commercialization of PRETDP

Hypothesis 1-b. Output diversity has a positive relationship with the projects' employment effect of PRETDP

4.2.3. Output quantity and quality

As South Korean government spends more on R&D expenditure, profound concern in R&D expenditure has been grown. South Korea has spent 24 billion dollar in public R&D and ranked as second among the OECD countries in terms of R&D expenditure per GDP [243,244] yet Korea ranked as 17th for technological infrastructure and 37th education [3]. These indicators show that Korea's R&D efficiency is low comparing to its R&D intensity, which means that it is necessary to revisit quality and quantity of both output and outcome performance to improve efficiency in public R&D expenditure.

To measure performance in R&D projects, both academic publications [203,204] and patents [205] are widely used as indicators in quantitative and qualitative approaches. Academic publications are typical output of academic research projects and considered to be one of major indicators in public R&D. In public R&D, both quantity and quality of journal publications are reflected on quantitative performance indicator for the purpose of comparison between different public R&D programs [203,204,206]. For academic publication quality, Impact Factor (IF) is often considered. The origin of SCI(E) index was thought to be started by Clarivate Analytics since 1958, when they provided database for journals with higher academic contribution [245]. As of now, journals included in SCI(E) index had thought to be an acknowledgement since many institutions used this databased to calibrate the quality of published articles. IF is a most common indicator of quantify the acknowledgement value of journal. When there are multiple number of articles, however, many other indexes are used to quantify the average journal value. For example, there is a Relative Field Impact Factor (rfIF), Modified Rank Normalized Impact Factor (mrnIF), Modified Relative Rank-normalized Impact Factor (mR2nIF) [246]. Although those factors are slightly different, simply using average IF could normally show the trend of information quality. Patents are open information resources that contain standardized information related to new ideas and technological developments, which makes them one of the most important output indicators of technology change and innovative activities [247,248]. Patents are often used as quantitative performance indicator for public R&D projects aiming for commercialization, because they can be applied on product or process innovation and may be able to create economic outcomes through licensing deals. For patent quality, SMART index is often used in South Korea for performance measurement of public R&D programs since it has chosen by Ministry of Science and ICT (MSIT) as a standardization method [249]. Patent quality index is often used in other countries. In United States, TR Patent Scorecard, created by MIT Technology Review and CHI Research Inc, is often used to evaluate patent score. Japanese patent analysis company called Patent Result also provides service for patent scoring [250]. It means patent quality is an important indicator for measuring output quality.

Hypothesis 2-a. Intellectual output has a positive relationship with the projects' commercialization of PRETDP

Hypothesis 2-b. Intellectual output has a positive relationship with the projects' employment effect of PRETDP

Hypothesis 3-a. Impact Factor average has a positive relationship with the projects' commercialization of PRETDP

Hypothesis 3-b. Impact Factor average has a positive relationship with the projects' employment effect of PRETDP

Hypothesis 4-a. SMART patent ratio has a positive relationship with the projects' commercialization of PRETDP

Hypothesis 4-b. SMART patent ratio has a positive relationship with the projects' employment effect of PRETDP

For experimental output, certification is often used as an evaluation measure for developed prototype. Certification is an official acknowledgement, provided with document, that developed product as a research output has met certain technical standard or protocol so that it is allowed to be produced or used for practical purpose [210]. Certification is given out from either government authorities or publicly trustable delegate institutions. The best-known institutions in South Korea would be Korea Laboratory Accreditation Scheme (KOLAS) and Korea Accreditation System (KAS.). The type of certification could be varied depend on target product, system, or technology. It could be also classified into national and private certification depend on legislated in law. Certification is evidence of showing whether research output has met targeted objective of technical performance. Previous research shows that certification is related to the patent activities [251] and return of investment of firms [210].

Hypothesis 5-a. Experimental output has a positive relationship with the projects' commercialization of PRETDP

Hypothesis 5-b. Experimental output has a positive relationship with the projects' employment effect of PRETDP

Hypothesis 6-a. Inclusion of public certification average has a positive relationship with the projects' commercialization of PRETDP

Hypothesis 6-b. Inclusion of public certification has a positive relationship with the projects' employment effect of PRETDP

Hypothesis 6-a. Inclusion of complete prototype average has a positive relationship with the projects' commercialization of PRETDP

Hypothesis 6-b. Inclusion of complete prototype has a positive relationship with the projects' employment effect of PRETDP

4.3. Methodology

4.3.1. Data Collection and Research Model

This study uses panel data obtained from the National Science &Technology Information Service (NTIS), originated from the “Energy R&D Result Analysis Reports” issued by the Korea Institute of Energy Technology Evaluation and Planning (KETEP). These data are constructed from the annual survey and evaluation reports responded by research participants in energy research projects funded by KETEP. The population of the survey includes public energy R&D projects completed within five years from the year of the survey (one survey per project conducted by principal investigator); consequently, there are overlaps in the population. This study used a third-year survey since the ex-post evaluation occurred three years after the project completion, the score this study used was a weighted measure for performance. The number of samples for this study was 430 projects completed in PRETDP between 2012 and 2016. These data contain various parameters, such as leader and participant organizations, investments from government and the private sector, number and quality of patents, academic papers, number of participating researchers, and other similar information.

4.3.2. Research model and variables

4.3.2.1. Dependent variables

This study analyzes R&D performance in two dimensions: *commercialization* and *employment effect;* their indicators are construed from the performance measurement model of Brown and Svenson (1988), as well as from actual performance index of PRETDP [19]. *Commercialization* is a binary variable showing whether project had delivered direct or indirect economic outcomes. To prove the creation of direct economic outcome, survey respondent should provide the proof document for sales, mostly tax invoice. For indirect economic outcome, survey respondent also needs to provide documents to show cost reduction, technology transfer, or import substitutes. This could be also shown by tax invoice, internally approved document, or reception of follow-up project from other institutions. These documents are managerial agency reviews the validity of information by checking tax invoice or other documents conforming to that standard. *Employment effect* is number of people newly employed for project commercialization by project participated firms. This means that employments for non-profit participant organization, such as post-doctorate employees, students, administrative workers, do not count as an employment effect. This outcome is related to political agenda of the government, creating more jobs in renewable energy sector. For the validation of employment, employment insurance document must be provided to show that it is a new employment. Part of role for doing annual survey is whether this employment effect is sustained with progressing years. This is continuous variable with various range so that this study used logarithm data transformation technique to minimize the skewness.

4.3.2.2. Independent variables

Output Diversity This study had referenced previous studies on product diversity and patent portfolio management [38,39], yet their methodology was far remoted from what this study is trying to observe. This study used four types of output quantity: academic publication, patent registration, certification, and prototype. By meaning of output diversity, it is important to know how many different outputs a project created. It is possible to make use of Blau's index once again, however, applying ratio on each output entity does not going to get what this study desire for because it is not feasible to make a weight on diverse types of output. Clearly, one academic publication would be much different from getting one certification. The efforts for getting one publication might be closer to have one patents than having one certification, however, there is no reference for such measure. Therefore, this study uses number of categories. So, output diversity index could be varied from zero to four. If a project only has patent and certification, then output diversity would be calculated as two. This will show whether having more kinds of output would be related to the acquisition of more outcome.

4.3.2.3. Moderating variable

Technology Difference Same as section 3, *technology difference* of incumbent R&D projects is considered as a moderating variable. *Technology difference* between two projects is defined by overlapped keywords because if two projects frequently use the same keyword, they are likely to have common ideas. This means that project with less sharing idea would have uniqueness in idea. Thus, this study defines technology difference of each keyword in the project as the degree to which the keyword connects to the other keywords. However, as more than one keyword is associated with the project, this study normalized the connectivity of keywords. Technology difference of the can be described as following equation, where N_i represents number of keywords in i^{th} R&D project:

$$Technology\ Difference = -\frac{1}{N_i}\sum_{j=0}^{N_i}\frac{sum\ of\ incident\ links}{sum\ of\ all\ nodes} \times degree\ of\ centrality_j$$

4.3.2.4. Control variables

Output Quantity Control This is a variable to compensate the limitation of output diversity variable. There are four types of output quantity variable as introduced in earlier paragraph: *intellectual output* (for academic publication and patent registration) and *experimental output* (certification and prototype). These categories can show which output affects the most on two different outcomes used in this study. The information on these variables is given in section 3, so description for these variables can be referred to it.

Output Quality Control This is also a variable to compensate the limitation of output diversity variable since both quantity and quality are important indicators of output. There are four types of output quality variable that matches with each output: *Impact Factor average, SMART patent ratio, inclusion of public certification,* and *inclusion of complete prototype*. *Impact Factor average* is often used in government project evaluation, and it could be traced with the DOI information given in survey report. Although there are numerous way of calibrate publication qualities, such as mrnIF or rfIF [252], average Impact Factor could be enough to show the value of academic value of individual project with reasonable discrepancy. For patent quality, *System to Measure, Analyze and Rate patent*

Technology (SMART) index developed by Korea Invention Promotion Association (KIPA). SMART index is often used in South Korea for performance measurement of public R&D programs, which is also included in performance index of PRETDP [19]. SMART index provides rank from AAA to CCC by relative evaluation among registered patents. The score is evaluated by committee run by KIPA with various expertise. The allocation of score is degree of rights, technology, and usability so how unique and how it meets current trends of technology will be an evaluation point. This study used SMART patent ratio of a project indicating that how many patent has been applied for relative evaluation. This is based on assumption that patent applied for SMART evaluation would be better than those did not apply for it. For certification, this study used *inclusion of public certificate* as a quality control variable. There are several types of public certification depending on authorities. However, those given by government authorities will be more difficult to earn than outsourced private authorities, since they have more credibility [210]. For prototype, complete prototype is added as a quality control variable. Survey criteria of *Energy R&D Result Analysis Reports* differentiates type of prototype with several categories: process, material/parts, module, element technology, and complete prototype. Among them, complete prototype is one that close to final product of a project often used for demonstration, while others are more of intermediate items takes only part of full prototype or a device or equipment used to develop the complete prototype. Therefore, this study infers the difference between complete prototype and other intermediary prototype.

R&D Project Control These are same variables used for previous section three, as they are common variable for controlling the characteristics of project. Variables used in this part are *government investment (log), private investment (log), project duration*, and *technology readiness level*. Detailed description on these variables can be found in section 3.

4.3.2.5. Hierarchical regression model

This study also constructed two regression equations to investigate relationship between output and two types of outcomes, which are commercialization and employment effect. A hierarchical regression model was employed for both equations, but two of them used different regression method due to difference in data type. Commercialization variable is binary data, composed of 0 or 1, so that binomial logistic regression is more proper way of estimation. On the other hand, employment effect is continuous variable, which is same as rest of dependent variables shown in section 3, so that using ordinary least square method would not be a problem. The statistically significant level is also designated as $|p| \leq 0.1$.This study uses the *Network X* package in Python to calculate the degrees of keyword network and SPSS for the hierarchical regression analysis as Equation below.

$$
\begin{aligned}
outcome_{com,emp} = \ & \alpha + \beta_{output.diversity}X_{output.diversity} + \beta_{intl.output}X_{intl.output} \\
& + \beta_{exp.output}X_{exp.output} + \beta_{edu.level}X_{edu.level} + \beta_{IFaverage}X_{IFaverage} \\
& + \beta_{SMART\ ratio}X_{SMART\ ratio} + \beta_{public.cert}X_{public.cert} \\
& + \beta_{com.prototype}X_{com.prototype} + \beta_{com.prototype}X_{com.prototype} \\
& + \beta_{gov.inv}X_{gov.inv} + \beta_{prv.inv}X_{prv.inv} + \beta_{prjt.dur}X_{prjt.dur} + \beta_{TRL}X_{TRL}
\end{aligned}
$$

Table 9. Variable statistics for study on R&D Output diversity

Variables		Descriptions	Reference	Obs.	Min	Max	Mean	Std.
Dependent Variable	Commercialization	whether project has created economic outcome in a project, such as sales, tech. transfer, or cost reduction (0 or 1)		430	0.00	1.00	0.30	0.46
	Employment Effect	Number of people hired by enterprises (exclude supporting employee hired by non-profit institution)		430	0.00	3.07	0.68	0.66
Output Diversity	Output Diversity	Counting kind of output quantity (scale from o to 4)		430	0.00	5.00	2.57	1.15
Control Variables - Output Quantity	Academic Publication (log)	Log scale on sum of academic publications	[144,225–227]	430	0.00	1.79	0.45	0.43
	Patent Registration (log)	Log scale on sum of patent registrations	[144,225–227]	430	0.00	1.85	0.41	0.37
	Certification (log)	Log scale on number of governments approved certificate, which could be found in standard.go.kr	[253]	430	0.00	1.41	0.49	1.61
	Prototype (log)	Log scale on number of prototypes built during research period		430	0.00	1.51	0.34	0.34
Control Variables - Output Quality	Average IF	Average impact factor of SCI journal published academic publication		430	0.00	15.89	2.33	2.34
	SMART Patent ratio	Number of Levelized patent divided by the total patent registered in a project	[249]	430	0.00	3.00	0.66	0.51
	Inclusion of Public Certification	project includes public or foreign certification (0 or 1)		430	0.00	1.00	0.06	0.24
	Inclusion of Complete Prototype	project includes complete prototype of not (0 or 1)		430	0.00	1.00	0.33	0.47
Control Variables - R&D project	Government investment (log)	Log scale on monetary public investment	[228,229]	430	0.14	2.45	1.20	0.37
	Private investment (log)	Log scale on monetary + in-kind (equipment, personnel) private investment	[228,232]	430	0.00	2.49	0.71	0.55
	Project duration	project periods in year	[163]	430	1.00	9.00	3.67	0.74
	Technical Readiness Level	Indicating maturity level of a particular technology (scale from 1 to 9) at project completion	[144,227]	430	2.00	9.0	4.99	1.75

4.4. Result and Discussion

4.4.1. Dataset analysis

This study uses 430 national R&D projects in the renewable energy sector. The detailed statistical description is shown in Table 9. The data transformation technique is used on continuous variables – *government investment*, *private investment*, *consortium size, academic publication, patent registration, certification,* and *prototype* – to compensate for its high dispersion, considering their value of skewness, kurtosis, and the difference between standard deviation and mean. The log transformation is used on these variables to prevent the distortion of the statistical relationship. The Pearson Correlation test has been conducted and provided in appendix table. Variance Inflation Factor (VIF) is also investigated to check multicollinearity; all value has been found to be less than 10.

4.4.2. Econometric analysis result on R&D outcome

This study constructed seven models to observe the change in adjusted R-squared value, as shown in Table 10. All model has been constructed for 430 projects in PRETDP. Model 1 to 3 are estimated results for commercialization, and Model 4 to 6 for employment effect. Model 1 and Model 4 are estimated with R&D project control variable only. Model 2 and Model 5 are estimated with the addition of output quantity and quality control variables. Model 3 and Model 6 are output diversity added model. To meet the condition of hierarchy regression model, the adjusted R-squared value must need to be improved or at least equal within the addition of variables. From this perspective, Model 1 → Model 2 showed increase in R-squared value; Model 2 → Model 3 also shoed increase in adjusted R-squared value; For the analysis of employment effect, Model 4 → Model 5 showed increase in R-squared value; and Model 5 → Model 6 also showed increase in R-squared value, meaning that addition of variables in all model is valid for the interpretation on discussion section. For the interpretation of coefficients, this study used p-value, known as the confidence interval, with the range from 90% to 100% interval. This study used above 99%, 99%, 95%, and 90% range for the interval range. Using this interval range with the sign of coefficients, this study analyzed the hypothesis. Detailed discussion and confirmation on hypothesis are provided in discussion sector.

Table 10. Regression analysis of R&D output diversity on outcome

Variable	Commercialization			Employment Effect		
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Diversity in R&D output						
Output diversity			0.342*			0.147***
Control – R&D Output Quantity						
Intellectual Output (log)			0.046			0.123
Academic Publication (log)		-0.677			-0.167	
Patent Registration (log)		0.380			0.188†	
Experimental Output (log)			0.135			0.006
Certification (log)		-0.894			-0.104	
Prototype (log)		0.121			0.042	
Control – R&D Output Quality						
Impact Factor average		0.129†	0.034		-0.017	-0.054***
SMART patent ratio		0.005	-0.171		-0.009	-0.085
Inclusion of Public Certification		1.986***	1.783**		0.165	0.087
Inclusion of Complete Prototype		0.604*	0.324		0.217**	0.106
Control – R&D Project						
Government investment (log)	0.078	0.304	-0.133	0.287*	0.427**	0.245†
Private investment (log)	0.887*	0.607	0.705	0.329***	0.175†	0.203*
Project duration	-0.346†	-0.440*	-0.442*	-0.157**	-0.145**	-0.138**
Technical Readiness Level	0.467***	0.451***	0.422***	0.029	0.012	0.000
Adjusted R-squared value	0.241	0.329	0.336	0.157	0.199	0.232

*** (Note) : *** $p \leq 0.00$; ** $0.00 < p \leq 0.01$; * $0.01 < p \leq 0.05$; † $0.05 < p \leq 0.1$**

4.5. Discussion

Table 11. Estimation summary of R&D output diversity and R&D outcome

Variables	Commercialization	Employment Effect	Direction of significant coefficients
	Confidence Interval of Estimated Coefficient (P-value) (%)		
Diversity in R&D output			
Output diversity			Identical
Control – R&D Output Quantity			
Intellectual Output (log)	Not Significant	Not Significant	-
Academic Publication (log)	Not Significant	Not Significant	-
Patent Registration (log)	Not Significant	Not Significant	-
Experimental Output (log)	Not Significant	Not Significant	-
Certification (log)	Not Significant	Not Significant	-
Prototype (log)	Not Significant	Not Significant	-
Control – R&D Output Quality			
Impact Factor average	Not Significant		Different
SMART patent ratio	Not Significant	Not Significant	-
Inclusion of Public Certification			Different
Inclusion of Complete Prototype	Not Significant	Not Significant	-
Control – R&D project			
Government investment (log)	Not Significant		Different
Private investment (log)	Not Significant		Different
Project duration			Identical
Technical Readiness Level		Not Significant	Different

* (Note) Confidence Interval (positive) = 90%; = 95%; = 99%; = above 99%
Confidence Interval (negative) = 90%; = 95%; = 99%; = above 99%

Discussion on identical factors Discussion points are those variables had identical 'direction of significant coefficients' in Table 11. *Output diversity* is shown to have positive effect on both commercialization and employment effect, although confidence level was little different. This is understandable since this finding is consistent with findings from previous studies [39], in a sense that moderate amount of diversity positively influences outcome performance. There are many diverse types of commercialization in PRETDP, more than just sales but also technology transfer or import substitution, so that single type of output quantity did not seem to directly affect outcome of projects in PRETDP. *Project duration* is also shown to have negative effectives on commercialization, which had negative relationship between input and outputs from analysis in section 3. This means delay in projects are not just bad for outputs but also affect the commercialization of the project in PRETDP.

Discussion on different factors Discussion points are those variables had different 'direction of significant coefficients' in Table 11. *Impact Factor average* has shown negative relationship with employment effect, while it has no significant relationship with commercialization. It has known that projects with enterprise leader organization has relatively low academic performance than projects with leader organization from university or government research institutes [254]. Employment effect is more related to the inclusion of enterprise organization in consortium than commercialization because commercialization can happen through technology transfer or reception of follow-up projects. But employment effect only can happen through direct employment from enterprises, so the outcome of employment effect is more depending on firm inclusion which may lower interest in pursuing quality in academic performance.

Inclusion of public certification has a positive effect on commercialization, but it was not for employment effect. In general, certification is known as an important factor for commercialization because it shows credibility of products that is safe enough to be used for business purpose [210]. However, employment effect is more related to public policy which is about economic growth [255], which might be indirectly related to commercialization but not necessarily. This result indicates that private certification has less impact on commercialization than public certification.

Control Variables showed some differences in estimation results as well. More government and private investment directly affect the employment effect, as hiring more people requires more monetary investment. Technical readiness level indicates how a project is technically ready for massive production, so it is more related to the commercialization than employment effect which could be occurred at any research stage.

Based on the analysis on the direction of significant coefficients, the result on the analysis of hypothesis has been summarized as in

Table **12**. Only hypothesis on output diversity and public certification has been confirmed, while others are rejected.

Table 12. Summary of hypothesis test for commercialization and employment effect

Hypothesis	**Result**
For commercialization	
H1-a. output diversity	**Positive**
H6-a. public certification	**Positive**
For employment effect	
H1-b. output diversity	**Positive**

∗ (Note) rest of hypothesis in H5 and H6 found to be not significant

4.6. Conclusion

Outputs are intermediate products of a research project that could act as check points for showing whether research activities of a project are heading right direction or will meet its objective. Previous literatures are mostly concentrated on input to output relationship, so that output to outcome relationship has been left out for the subject of study despite its importance in strategic management of public R&D. Considering limited resources are available in public sector, studying the relationship between output and outcome could reduce the risk of uncertainty and enhance performance.

This paper assessed the relationships between R&D output and outcome in PRETDP in terms of diversity, quantity, and quality of outputs. Two types of output are applied in this study: intellectual and experimental. Intellectual outputs are sum of academic publication and patents, whereas experimental outputs are composed of certifications and prototypes. Both outputs are considered in quantity and quality. Commercialization and employment effect were considered for outcome variables. Using data from the Korea institute of Energy Technology Evaluation and Planning, this study analyzed 430 projects in PRETDP completed between 2009 and 2015 by applying hierarchical regression analysis. This study found that there is a similarity between outcomes of PRETDP. *Output diversity* has influence on commercialization and employment effects of all projects. As previous studies suggested that moderate amount of diversity positively influences outcome performance, this finding confirms that such result is also applicable in PRETDP. On the other hand, there were many differences. *Impact Factor average* has shown negative relationship with employment effect while it did not show significant impact for commercialization, which may have been caused by mandatory of firms' participation in research consortium for creating employment effect. Also, commercialization was positively affected by *inclusion of national certification*, while employment effect was not affected by it. This means that credibility of products is important for PRETDP, and private certification provides less credibility than national certification.

Output diversity has a positive impact on outcome. More outputs could increase credibility of products in various perspectives, so it enhances commercialization of projects in PRETDP. Having diversity in outputs means more tasks to fulfill in the research work, so more human resources will be required to do the work. So, promoting diversity in outputs are recommendable tactics for PRETDP so that it should be accounted at project evaluation stage.

Output quality acted differently on outcomes of PRETDP. Credibility of product is a principal factor of commercialization. From managerial perspective, how well-organized the project is important to discrete projects with possibilities in commercialization for all projects' group. Quality of academic publication was not significant for promoting employment effects of both all projects' group and core project's group. These findings could inform managers what output to focus for promoting more desirable outcome.

The findings of this study highlight the relationship between diversity and R&D performance, which are useful in the public R&D managerial sector. By pioneering on the relationship between output diversity and outcome, it could open new research stream on performance measurement and could enrich the managerial implications to strategic management of PRETDP. By providing added information to policymakers, this study could contribute to the improvement of the public renewable energy R&D managerial system in South Korea.

Chapter 5. Consideration on the strategic R&D management of PRETDP: focusing on technology difference and core competency

5.1. Introduction

Public R&D management has been evolved in a way to intensify the control over research projects which can be explained by management control behavior, the part of the organization control theory. Strategic R&D management has closely related to management of technology. Although there are no simple rules for public R&D management [1], strategic R&D management is about figuring out how to do better portfolio management. In this perspective, it is significant for R&D managers to know how different technologies [75] are and what are core technologies [76].

The main purpose of this study is to redefine the relationship between input-to-output and output-to-outcome relationship of Public Renewable Energy Technology Development Program (PRETDP) by using technology difference as a moderating variable and by making comparison between all projects' and core projects' group. This research analyzed 430 projects that participated in PRETDP, which has initiated project in 2009 and completed by

2015. This study shares dependent, independent, and control variables from two previous studies introduced in Chapter 3 and Chapter 4. However, this study added technology difference as a moderating variable, which is calculated by centrality of keywords for each project. Also, this study extracted core projects from all projects of PRETDP based on essential keywords, using “cost-reduction” or “power generation efficiency improvement.” Then, this study made comparison between this core projects’ group with all projects’ group to see if there are any differences in managerial point.

This study has combined core competency and technology difference to develop strategic management plan for PRETDP. Although previous literatures have dealt with technology distance or core competency, but they did not have put together to find managerial insights, especially in public domain. This study expanded the discussion between technology difference and innovation performance [225,256] by adding analysis on outcome. Also, this study applied this definition onto core projects in R&D portfolio management by following footsteps of previous works [77,257]. This paper is structured as follows: first, review on the literature of strategic R&D management with hypotheses development. Then, data source and methodology are elaborated, as well as variable descriptions and econometrical analysis. Finally, discussions and conclusions are attached.

5.2. Technology difference and core competency

The academic discussion on technology difference is derived from the idea of the exploration and exploitation as well. In organizational studies, exploration and exploitation are often used to explain activities of organizations seeking a competitive advantage over others [78]. Exploration strategies are associated with search, discovery, experimentation, and the development of new knowledge. In contrast, exploitation strategies involve activities that seek the refinement and extension of existing knowledge and are associated with convergent thinking [79]. There are two different views on the relationship between exploration and exploitation. Some researchers argue that exploration and exploitation strategies can be mutually supportive, meaning that each strategy would help leverage the effect of another [258,259]. However, major research streams, including March, consider that exploration and exploitation are different and incompatible [78,260,261]. The notion of exploration and exploitation is used in many different industrial sectors. These studies mostly analyze organizational behaviors [262–264]. However, some are extended to organizational performance [260,265], and others towards R&D activities [266].

When it comes to the discussion of empirical study, technological difference refers to the extent of diversification of an organization's technology base [75,267]. As technological competitiveness of the firms became significant issue, several previous studies have dealt with corporate technological diversification [77,268,269]. Those studies either uses patent classification or index on technology distance to reveal their relationship with product innovation or innovation performance [267,269,270]. Granstrand (1998) argues that technology diversification strategy can improve innovation efficiency of organizations, since recombination of various technologies can stimulate more creative ideas to stimulate innovation. Gambardella and Torrisi (1998) provide empirical evidence that corporate performance is positively related to technological diversification, as well as positive relation between corporate performance and the technology-focused strategy of business operations. But at the same time, many agrees that excessive technological diversification would have detrimental impacts on firm performance from the perspectives of coordination costs and core competence [40,77]. These studies imply that tracking similar or diversified research paths from previous projects would help R&D managers predict how these choices on the path affect the performance of individual research projects.

Core Competencies (CCs) can be defined as consisting of bodies of technological expertise, both in product and process, and the organizational capacity to deploy that expertise effectively [37]. Depending on its context, CCs can be construed as technological character or subdivision of an organization. As Tallman (1996) suggested, they are embellished and strengthened through continued use, meaning that they are subject to positive returns, and are therefore to some extent firm-specific and non-transferable.

If we expand such definition to research activities, CCs can be discussed in the context of firm's strategic decision for portfolio management, or for project management of R&D activities. From this perspective, firms can efficiently accumulate and strengthen its technological knowledge by applying different managerial metrics on small number of core technology fields [77]; figuratively speaking, a firm should pick out similar eggs and put into one basket to receive benefit of unified governance mechanism [271]. For better management of portfolio, previous study also suggest that managers must ensure that each part of the portfolio is integrated into and contributes to the core competences of the firm [257]. Summarizing suggestions of previous studies, core projects must be distinguished in its research portfolios, as they could be link to core competency of an organization – or in public R&D case, may be able to interpret as a core competency of a program.

5.3. Strategic management of PRETDP

From earlier study, it has become clear that strategic R&D management has close link technology management. To develop effective R&D management strategy, it is important to know how different technologies [75] are and what are core technologies [76]. From this perspective, technology difference and core competency should get attention to the extent of strengthen management strategy of PRETDP.

Previous study implied that tracking similar or diversified research paths from previous projects would help R&D managers predict how these choices on the path affect the performance of individual research projects. This study have mentioned several studies relating to technology difference and innovation performance [225,256,270], but some of previous study showed positive relationship between patents and economic outcome in public R&D projects [210,272]. Although patent is not a single factor affecting projects' commercialization, this could work as a foundation for organization's competitiveness to discuss further commercialization of the relative technology.

This study has applied the concept of core competency on R&D portfolio management by following footsteps of previous works [77,257], so this study aims to figure out what are different characteristics of core projects in terms of input and output resources. Regarding literature on core competency, a previous study relating to innovation performance were introduced in section 3 [273], but there are few more research stream on firm's performance regarding to sales and cost reduction [76,274]. Although these studies were concentrated on individual firm's performance rather than R&D consortium, core competency could have positive impact on firm's performance. Based on these findings, this study could infer that core projects would be an important asset of portfolio of PRETDP; therefore, it is important to know how to manage those projects more effectively.

Hypothesis 1. Technology difference has more positive relationships with R&D team diversity of core projects' group than all projects' group for outputs of PRETDP

Hypothesis 1-a. Technology difference would moderate more positive relationship between demographic diversity and outputs of core projects' group than all projects' group of PRETDP

Hypothesis 1-b. Technology difference would moderate more positive relationship between collaboration diversity and outputs of core projects' group than all projects' group of PRETDP

Hypothesis 2. Technology difference has more positive relationships with R&D team diversity of core projects' group than all projects' group for outcomes of PRETDP

Hypothesis 2-a. Technology difference would moderate more positive relationship between output diversity and outcomes of core projects' group than all projects' group of PRETDP

Hypothesis 2-b. Technology difference would moderate more positive relationship between output quantity and outcomes of core projects' group than all projects' group of PRETDP

Hypothesis 2-c. Technology difference would moderate more positive relationship between output quality and outcomes of core projects' group than all projects' group of PRETDP

5.4. Methodology

5.4.1. Data Collection and Research Model

This study uses panel data obtained from the National Science &Technology Information Service (NTIS), originated from the “Energy R&D Result Analysis Reports” issued by the Korea Institute of Energy Technology Evaluation and Planning (KETEP). These data are constructed from the annual survey and evaluation reports responded by research participants in energy research projects funded by KETEP. The population of the survey includes public energy R&D projects completed within five years from the year of the survey (one survey per project conducted by principal investigator); consequently, there are overlaps in the population. This study used a third-year survey since the ex-post evaluation occurred three years after the project completion, the score this study used was a weighted measure for performance. The number of samples for this study was 430 projects completed in PRETDP between 2012 and 2016. These data contain various parameters, such as leader and participant organizations, investments from government and the private sector, number and quality of patents, academic papers, number of participating researchers, and other similar information.

5.4.2. Research model and variables

5.4.2.1. Dependent variables

This study re-analyzed the studies in previous two chapters with a new moderating variable and a different group. Therefore, it shares same independent variables used in previous studies: *intellectual output*, *experimental output, commercialization,* and *employment effect*. *Intellectual output* is constructed using the weighted sum of intellectual outcomes, including the number of patents and research papers. *Experimental output* indicates intermediate products created by actions of lab test and development. This study used certification and prototype to actualize experimental output. Certification is an official acknowledgement, provided with document, showing developed product in a project has met certain technical standard or protocol to be allowed for business use [210]. Prototype is an intermediate product of item actualization of research activities, which often requires certification for proof. *Commercialization* is a binary variable showing whether project had delivered direct or indirect economic outcomes. To prove the creation of direct economic outcome, survey respondent should provide the proof document for sales, mostly tax invoice. For indirect economic outcome, survey respondent also needs to provide documents to show cost reduction, technology transfer, or import substitutes. *Employment effect* is number of people newly employed for project commercialization by project participated firms. This means that employments for non-profit participant organization, such as post-doctorate employees, students, administrative workers, do not count as an employment effect. This outcome is related to political agenda of the government, creating more jobs in renewable energy sector.

5.4.2.2. Independent variables

Demographic Diversity This study used the index of diversity proposed by Blau (1977), which show how evenly members are distributed in different categories. For instance, gender diversity by considering ratio of team members in various categories. So, for instance, Blau's diversity index for gender only has two categories (male and female) so that the index range could be varied from 0 (where an R&D team is composed of a single gender) to 0.5 (where a team has a balanced number of both males and females).

Collaboration Diversity UIG relationships are composed of multiple combinations from *university (U), industry (I). and government research institutes (G).* This study re-categorized these combinations by behavioral characteristics of consortium [2]:

homogeneous collaboration, heterogeneous collaboration, and *non-collaboration*. *Homogeneous collaboration* indicates form of consortium with same motivation; this study used *for-profit* and *non-profit. Heterogeneous collaboration* is a type of consortium form with different motivation; this could be specified into *bilateral* and *trilateral* collaboration in the context of UIG relationship. *Bilateral* contains one entity from *non-profit* and another from *profit*, which indicate *(I) to (U)* and *(I) to (G)*. *Trilateral* contains all three entities of UIG relationship. *Bilateral* and *Trilateral* type of collaboration is in demand when a project requires increases both in the scale of economies and the complexity of goals, which are also most common type of consortium in PRETDP.

Output Diversity This study had referenced previous studies on product diversity and patent portfolio management [38,39], yet their methodology was far remoted from what this study is trying to observe. This study used four types of output quantity: academic publication, patent registration, certification, and prototype. By meaning of output diversity, it is important to know how many different outputs a project created. It is possible to make use of Blau's index once again, however, applying ratio on each output entity does not going to get what this study desire for because it is not feasible to make a weight on diverse types of output. Clearly, one academic publication would be much different from getting one certification. The efforts for getting one publication might be closer to have one patents than having one certification, however, there is no reference for such measure. Therefore, this study uses number of categories. So, output diversity index could be varied from zero to four. If a project only has patent and certification, then output diversity would be calculated as two. This will show whether having more kinds of output would be related to the acquisition of more outcome.

5.4.2.3. Moderating variable

Technology Difference In this study, *technology difference* of incumbent R&D projects is considered as a moderating variable. The definition for technology difference is given in the literature review section: it is showing how unique project subject is in terms of project keywords. This study employs network analysis to measure the connectivity between nodes (projects) and keywords (edges) to distinguish the uniqueness of the project subject. Previous studies showed multiple ways to distinguish characteristics of subjects: some used questionnaire responses of key personnel to evaluate the focus of subject [275–277]. Others used objective proxies such as the degree to which search activity is technologically and organizationally bounded [278], or as the depth and breadth of technological search activity [279]. However, these methodologies have been criticized for their lack of applicability outside their respective contexts [260] and inconsistency with the conceptual definitions of subject [258]. Therefore, more recommendable way to distinguish technology difference would be applying a context-based approach. The contents analysis method of counting and scoring words and word frequencies are effective in many studies [280,281] and are proven to capture organizational attributes that are difficult to quantify otherwise [282]. Previous studies on exploration and exploitation regarding the financial performance of organizations have used word frequencies in articles to distinguish them [260]. Similar trends for methodology can be seen in the study of innovation performance as well. The text-mining-based similarity is a new method for calculating the similarities capturing hidden properties. Bhattacharyya et al. (2011) suggested the measurement of user similarity based on frequently used keywords. This led to a conclusion that the methodology of this study could use this approach to accurately differentiate technology difference.

Technology difference between two projects is defined by overlapped keywords because if two projects frequently use the same keyword, they are likely to be in the same group. This is effective when the meaning of a keyword is consistent regardless of the context.

Thus, this study defines technology difference of each keyword in the project as the degree to which the keyword connects to the other keywords. However, as more than one keyword is associated with the project, this study normalized the connectivity of keywords. Technology difference of the can be described as following equation, where N_i represents number of keywords in i^{th} R&D project:

$$Technology\ Difference = -\frac{1}{N_i}\sum_{j=0}^{N_i}\frac{sum\ of\ incident\ links}{sum\ of\ all\ nodes} \times degree\ of\ centrality_j$$

5.4.2.4. Control variables

Output Quantity Control This is a variable to compensate the limitation of output diversity variable. There are four types of output quantity variable as introduced in earlier paragraph: *intellectual output* (for academic publication and patent registration) and *experimental output* (certification and prototype). Specific details of variables are shown in chapter 4.

Output Quality Control This is also a variable to compensate the limitation of output diversity variable since both quantity and quality are important indicators of output. There are four types of output quality variable that matches with each output : *Impact Factor* *average, SMART patent ratio, inclusion of public certification,* and *inclusion of complete prototype*. *Impact Factor average* shows the value of academic value of individual project with reasonable discrepancy. *SMART index* is often used in South Korea for performance measurement of public R&D programs. *Inclusion of public certification* means more credibility in certification. *Inclusion of complete prototype* means whether project has developed commercially prepared prototype. Specific details of variables are shown in chapter 4.

R&D Team Control This study controlled few factors related to research consortium and researchers in consortium. *Consortium size (log)*, *participants from industry*, l*eader's Experience in PRETDP*, and *number of researcher (log)* are used as R&D team control variable, and specific details for these variables are given in chapter 3.

R&D Project Control These are same variables used for chapter 3 and 4, as they are common variable for controlling the characteristics of project. Variables used in this part are *government investment (log), private investment (log), project duration*, and *technology readiness level*. Detailed description on these variables can be found in chapter 3 and 4.

5.4.2.5. Hierarchical regression model

This study also constructed two regression equations to investigate relationship between input-to-output and output-to-outcome for core projects' group and all projects' group. Technology difference was also added as a moderating variable for all equations. The statistically significant level is also designated as $|p| \leq 0.1$.This study uses the *Network X* package in Python to calculate the degrees of keyword network and SPSS for the hierarchical regression analysis as equation below.

$$output_{intl,exp_{i,j}} = \alpha + \beta_{gender}X_{gender} + \beta_{age}X_{age} + \beta_{edu.background}X_{edu.background} + \beta_{edu.level}X_{edu.level}$$

$$+ \beta_{homogeneous.col}X_{homogeneous.col} + \beta_{heteorogeneous.col}X_{heterogeneous.col}$$

$$+ \beta_{con.size}X_{con.size} + \beta_{part.ind}X_{part.ind} + \beta_{num.res}X_{num.res} + \beta_{gov.inv}X_{gov.inv}$$

$$+ \beta_{prv.inv}X_{prv.inv} + \beta_{prjt.dur}X_{prjt.dur} + \beta_{TRL}X_{TRL} + \beta_{tech.diff}X_{tech.diff}$$

$$outcome_{com,emp_{i,j}} = \alpha + \beta_{out.div}X_{out.div} + \beta_{intl.out}X_{intl.out} + \beta_{exp.out}X_{exp.out} + \beta_{edu.level}X_{edu.level}$$

$$+ \beta_{IFaverage}X_{IFaverage} + \beta_{SMART\ ratio}X_{SMART\ ratio} + \beta_{public.cert}X_{public.cert}$$

$$+ \beta_{com.prototype}X_{com.prototype} + \beta_{com.prototype}X_{com.prototype} + \beta_{gov.inv}X_{gov.inv}$$

$$+ \beta_{prv.inv}X_{prv.inv} + \beta_{prjt.dur}X_{prjt.dur} + \beta_{TRL}X_{TRL} + \beta_{tech.diff}X_{tech.diff}$$

$$, where\ i = all\ projects'group\ and\ j = core\ projects'group$$

5.5. Result and Discussion

5.5.1. Econometric analysis result on moderating effect and core projects

This essay expanded analysis in chapter 3 by adding technology difference as a moderating variable and make comparison between estimation on all PRETDP projects and core projects. Cross terms of moderating effects are considered for R&D team diversity variables. Hierarchical Regression Analysis is also applied to observe the change in adjusted R-squared value. If R-squared value is decrease within addition of cross terms, this study considered that moderating effect is not observable. This study also used above 99%, 99%, 95%, and 90% range for the interval range for confidence interval.

Intellectual output This estimation contains six models as shown in Table 13. First three models are for all 430 projects in PRETDP, while next three models are for 100 core projects in PRETDP. Model 1 and 4 is control and R&D team diversity included model; estimation coefficient for Model 1 is same as Model 7 in Table 5. Model 2 and 5 is technology difference added model from Model 1 and 6, respectively. Model 3 and 7 is cross term of R&D team diversity added model from Model 2 and 5, respectively. To meet the condition of hierarchy regression model, the adjusted R-squared value must need to be improved or at least equal within the addition of moderating variable and cross terms. From this perspective, Model 1 → Model 3 was decreased so that moderating effect cannot be observed. On the other hand, Model 4 → Model 6 showed increase in R-squared value, indicating that moderating effect can be observed. Detailed discussion and confirmation on hypothesis are provided in discussion sector.

Experimental output This estimation also contains six models as shown in Table 14. Same as before, first three models are for all 430 projects in PRETDP while next three models are for 100 core projects in PRETDP. Model 1 and 4 is control and R&D team diversity included model, l; estimation coefficient for Model 1 is same as Model 7 in Table 6. Model 2 and 5 is technology difference added model from Model 1 and 6, respectively. Also, Model 3 and 7 is cross term of R&D team diversity added model from Model 2 and 5, respectively. For hierarchical regression analysis, the adjusted R-squared values are also compared to check the validity. Model 1 → Model 3 was increased so that moderating effect is valid for this model. On the other hand, Model 4 → Model 6 showed slight decrease in R-squared value, indicating that moderating effect cannot be found. Detailed discussion and confirmation on hypothesis are provided in discussion sector

Table 13. Analysis result on intellectual output of all and core projects group

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	PRETDP All Projects				PRETDP Core Projects	
Diversity in R&D Team – Demography						
Gender	0.518***	0.517***	0.555**	0.549†	0.489†	0.162
Age	-1.088***	-1.095***	-1.032***	-1.123**	-1.164**	-1.199*
Education background	-0.043	0.041	-0.009	0.151	0.073†	0.293†
Education level	0.162	0.157	-0.047	0.051	0.019	-0.279
Diversity in R&D Team – Collaboration						
Homogeneous collaboration	0.001	0.001	0.056	0.114	0.109	0.070
Heterogeneous collaboration	-0.044	-0.043	-0.014	0.051	0.081	0.066
Non-collaboration (baseline)						
Diversity in Research Subject						
Technology Difference		0.009	0.054		0.052**	0.265
Technology Difference x Gender			0.022			-0.209
Technology Difference x Age			0.042			-0.103
Technology Difference x Edu. Background			0.040			0.147
Technology Difference x Edu. Level			0.198			-0.188
Technology Difference x Homogeneous			0.053			-0.052
Technology Difference x Heterogeneous			0.032			-0.038
Control – R&D Team						
Consortium size (log)	0.209**	0.208**	0.204**	0.259	0.176	0.194
Participants from industry	-0.131	-0.128	-0.130	-0.421*	-0.402*	-0.382*
Leader's experience in RE R&D	0.009	0.009	0.009	0.040†	0.049*	0.050*
Number of researchers (log)	0.380***	0.382***	0.389***	0.071	0.056	0.084
Control – R&D Project						
Government investment (log)	0.439***	0.442***	0.429***	0.406	0.426	0.355
Private investment (log)	-0.130†	-0.133†	-0.132†	0.073	0.058	0.042
Project duration	-0.076**	-0.076**	-0.077**	-0.030	-0.017	-0.005
Technical Readiness Level	-0.002	-0.002	-0.001	0.006	0.021	-0.017
Adjusted R-squared value	0.451	0.451	0.446	0.548	0.579	0.565

*** (Note) : *** p ≤ 0.00; ** 0.00 < p ≤ 0.01; * 0.01 < p ≤ 0.05; † 0.05 < p ≤ 0.1**

Table 14. Analysis result on experimental output of all and core projects group

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	PRETDP All Projects			PRETDP Core Projects		
Diversity in R&D Team – Demography						
Gender	0.072	-0.211†	-0.146	0.062	0.063	-0.118
Age	-1.243*	-0.264†	-0.548**	-0.003	-0.002	-0.546
Education background	-0.089	0.091	0.025	0.345†	0.346†	0.189
Education level	-0.042	-0.046	0.074	-0.678*	-0.678*	-0.166
Diversity in R&D Team – Collaboration						
Homogeneous collaboration	0.049	0.049	0.039	-0.002	-0.002	-0.038
Heterogeneous collaboration	0.106*	0.106*	0.102	0.074	0.074	0.004
Non-collaboration (baseline)						
Diversity in Research Subject						
Technology Difference		0.007	0.088		0.000	0.123
Technology Difference x Gender			0.054			0.246
Technology Difference x Age			-0.224*			-0.291
Technology Difference x Edu. Background			-0.059			-0.068
Technology Difference x Edu. Level			0.104			0.344
Technology Difference x Homogeneous			-0.016			-0.072
Technology Difference x Heterogeneous			0.013			0.099
Control – R&D Team						
Consortium size (log)	-0.002	-0.002	-0.002	0.112	0.113	0.068
Participants from industry	0.369***	0.371***	0.386***	0.487**	0.487**	0.584***
Leader's experience in RE R&D	0.031***	0.031***	0.031***	0.050*	0.050*	0.048*
Number of researchers (log)	-0.026	-0.025	-0.048	0.098	0.098	-0.223
Control – R&D Project						
Government investment (log)	0.192†	0.194†	0.232*	0.409	0.409	0.576*
Private investment (log)	0.011	0.009	0.001	-0.161	-0.161	-0.189
Project duration	-0.051*	-0.051*	-0.052*	-0.008	-0.008	-0.030
Technical Readiness Level	0.020*	0.019*	0.018†	0.027	0.027	0.025
Adjusted R-squared value	0.328	0.328	0.330	0.434	0.428	0.426

*** (Note) : *** p ≤ 0.00; ** 0.00 < p ≤ 0.01; * 0.01 < p ≤ 0.05; † 0.05 < p ≤ 0.1**

5.5.2. Econometric analysis result on moderating effect and core projects

This essay expanded analysis in chapter 4 by technology difference as a moderating variable and make comparison between estimation on all PRETDP projects and core projects. Cross terms of moderating effects are considered for output diversity and output quality variables. Hierarchical Regression Analysis is also applied to observe the change in adjusted R-squared value. If R-squared value is decrease within addition of cross terms, this study considered that moderating effect is not observable. This study also used above 99%, 99%, 95%, and 90% range for the interval range for confidence interval.

Commercialization This estimation contains six models as shown in Table 15. First three models are for all 430 projects in PRETDP, while next three models are for 100 core projects in PRETDP. Model 1 and 4 is control and R&D team diversity included model; estimation coefficient for Model 1 is same as Model 3 in Table 10. Model 2 and 5 is technology difference added model from Model 1 and 4, respectively. Model 3 and 6 is cross term of R&D output added model from Model 2 and 5, respectively. To meet the condition of hierarchy regression model, the adjusted R-squared value must need to be improved or at least equal within the addition of moderating variable and cross terms. From this perspective, Model 1 → Model 3 was increased so that moderating effect can be observed. On the other hand, Model 4 → Model 6 showed increase in R-squared value, indicating that moderating effect can also be observed. Detailed discussion and confirmation on hypothesis are provided in discussion sector.

Employment Effect This estimation also contains six models as shown in Table 16. Same as before, first three models are for all 430 projects in PRETDP while next three models are for 100 core projects in PRETDP. Model 1 and 4 is control and R&D output diversity included model, l; estimation coefficient for Model 1 is same as Model 6 in Table 10. Model 2 and 5 is technology difference added model from Model 1 and 4, respectively. Also, Model 3 and 6 is cross term of R&D team diversity added model from Model 2 and 5, respectively. For hierarchical regression analysis, the adjusted R-squared values are also compared to check the validity. Model 1 → Model 3 was increased so that moderating effect is valid for this model. On the other hand, Model 4 → Model 6 showed decrease in R-squared value, indicating that moderating effect cannot be found. Detailed discussion and confirmation on hypothesis are provided in discussion sector.

Table 15. Analysis result on commercialization of all and core projects group

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	PRETDP All Projects			PRETDP Core Projects		
Diversity in R&D Output						
Output diversity	0.342*	0.365*	0.444†	-0.212	-0.189	0.165
Control – R&D Output Quantity						
Intellectual Output	0.046	0.019	0.103	0.669	0.751	0.370
Experimental Output	0.135	0.128	-0.845	1.255	1.423	0.958
Control – R&D Output Quality						
Impact Factor average	0.034	0.033	0.042	0.144	0.152	0.221
SMART patent ratio	-0.171	-0.159	-0.252	1.011	1.173†	0.745†
Inclusion of National Certification	1.783**	1.658**	2.301**	2.223	2.162	2.172
Inclusion of Complete Prototype	0.324	0.324	0.367	-0.035	-0.138	-0.356
Diversity in Research Subject						
Technology Difference		-0.176†	-0.096		-0.262	-0.660
Technology Difference x Output diversity			0.028			0.378
Technology Difference x Intellectual Output			0.125			-0.642
Technology Difference x Experimental Output			-0.768†			-0.151
Technology Difference x Impact Factor average			0.005			0.127
Technology Difference x SMART patent ratio			-0.037			-0.275
Technology Difference x Inclusion of National Certification			0.496			-0.751
Technology Difference x Inclusion of Complete Prototype			0.045			-0.227
Control – R&D Project						
Government investment (log)	-0.133	-0.188	-0.084	-1.100	-1.419	-1.682
Private investment (log)	0.705	0.720	0.655	2.307†	2.329†	2.631†
Project duration	-0.442*	-0.438*	-0.435*	-1.014	-1.012	-0.818
Technical Readiness Level	0.422***	0.423***	0.418***	0.490*	0.558**	0.566**
Adjusted R-squared value	0.336	0.344	0.356	0.571	0.585	0.607

*** (Note) : *** p ≤ 0.00; ** 0.00 < p ≤ 0.01; * 0.01 < p ≤ 0.05; † 0.05 < p ≤ 0.1**

Table 16. Analysis result on employment effect of all and core projects group

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	PRETDP All Projects				PRETDP Core Projects	
Diversity in R&D Output						
Output diversity	0.147***	0.108*	0.086	0.214*	0.216*	0.278†
Control – R&D Output Quantity						
Intellectual Output	0.123	0.142†	0.083	-0.045	-0.090	-0.083
Experimental Output	0.006	0.215†	0.272	-0.254	-0.287	-0.285
Control – R&D Output Quality						
Impact Factor average	-0.054***	-0.052***	-0.050**	-0.049†	-0.048†	-0.064†
SMART patent ratio	-0.085	-0.058	-0.007	-0.194	-0.227	-0.290
Inclusion of National Certification	0.087	0.048	0.267	-0.200	-0.157	0.238
Inclusion of Complete Prototype	0.106	0.075	0.155	0.152	0.169	0.055
Diversity in Research Subject						
Technology Difference		-0.020	-0.010		0.046	-0.024
Technology Difference x Output diversity			-0.018			0.039
Technology Difference x Intellectual Output			-0.054			0.050
Technology Difference x Experimental Output			0.032			0.071
Technology Difference x Impact Factor average			0.002			-0.010
Technology Difference x SMART patent ratio			0.048			-0.062
Technology Difference x Inclusion of National Certification			0.111			0.173
Technology Difference x Inclusion of Complete Prototype			0.069			-0.138
Control – R&D Project						
Government investment (log)	0.245†	0.204	0.176	0.859*	0.924**	0.915*
Private investment (log)	0.203*	0.190*	0.194*	0.104	0.114	0.079
Project duration	-0.138**	-0.123**	-0.118**	-0.371**	-0.369**	-0.296*
Technical Readiness Level	0.000	0.000	0.001	0.040	0.052	-0.049
Adjusted R-squared value	0.232	0.236	0.238	0.285	0.288	0.264

*** (Note) : *** $p \leq 0.00$; ** $0.00 < p \leq 0.01$; * $0.01 < p \leq 0.05$; † $0.05 < p \leq 0.1$**

5.6. Discussion

5.6.1. The moderating effect of technology difference on R&D output

Table 17. Summary of findings on technology diversity and core projects on output

Variable	All Projects INT	All Projects EXP	Core Projects INT	Core Projects EXP	Direction of significant coefficient
	Confidence Interval of Estimated Coefficient (P-value) (%)				
R&D Team Diversity – Demography					
Gender				NS	Similar
Age				NS	Similar
Education background	NS	NS			Different
Education level	NS	NS	NS		Different
R&D Team Diversity – Collaboration					
Homogeneous collaboration	NS	NS	NS	NS	-
Heterogeneous collaboration	NS		NS	NS	Different
Non-collaboration (baseline)	NS	NS	NS	NS	-
Research Subject Diversity					
Technology Difference	NS	NS		NS	Different
Age x Technology Difference	NS		NS	NS	Different
Control – R&D Team					
Consortium size (log)		NS	NS	NS	Different
Participants from industry	NS				Similar
Leader’s experience in RE R&D	NS				Similar
Number of researchers (log)		NS	NS	NS	Different
Control – R&D Project					
Government investment (log)			NS	NS	Different
Private investment (log)		NS	NS	NS	Different
Project duration			NS	NS	Different
Technical Readiness Level	NS		NS	NS	Different

* (Note 2) Confidence Interval (positive) = 90%; = 95%; = 99%; = above 99%
Confidence Interval (negative) = 90%; = 95%; = 99%; = above 99%

Discussion on identical/similar factors Discussion points are those variables had identical or similar ‘direction of significant coefficients’ in Table 17. ‘All projects’ indicates inclusion of all 430 projects in PRETDP, while ‘core projects’ indicates those 100 projects have keywords of efficiency or cost reduction. Variables had identical or similar effect for both all projects and core projects are *gender diversity, participants from industry, leader's experience in RE R&D, project duration,* and *technical readiness level.* The observations on these variables are already made in previous discussion section, so it seems unnecessary to have a redundant discussion.

Discussion on different factors These are critical points of this study that shows difference between all projects and core projects. These variables had difference 'direction of significant coefficients' in Table 17. *Education background diversity* was insignificant in all projects group, while it shows significancy in core projects group. This study scrutinized this detail and tried additional regression on subcategories of educational background. From additional analysis, this study found that engineering major was significant at all projects group while it did not show significancy in core projects group. This could be interpreted as core projects group need to less rely on engineering majors and acceptable to researchers with more various educational background.

Educational level diversity is found to be insignificant in all projects group, while it was negative in core projects group. Core projects group showed a negative relationship between educational diversity and experimental output, because projects in this group – from the analysis of comparison of statistics between two groups – have more master and Ph. D researchers than all projects in average. If the comparison is made only for projects with experimental outputs greater than zero, the difference in average number of master and Ph. D. researchers is even larger between all projects and core projects. This could be construed as more professional quality of researchers are demanded in core projects than all projects group.

Heterogeneous collaboration, consortium size, and *number of researchers* showed differences between all projects and core projects group that could be linked together to discuss differences. *Heterogenous collaboration* found to be effective for creating experimental output in all projects group because of the inclusion of profit organization, which this study interpreted in earlier section. This result could be linked to difference in consortium size and number of researchers between groups, where core projects did not have any significancy for both while all projects group did show significance. It means that all projects group want more researcher to be involved. From previous study of Sakaibara (1997), heterogeneous collaboration is linked with skill-sharing motives of R&D consortium formation in which the consortium wants to cooperate for the resource accumulation, or learning in an R&D consortium [2]. Meanwhile, core projects groups have less tendency to seek for heterogeneous collaboration nor involvement of more organization or researchers, meaning that these projects want to secure their new knowledge only to small number of individuals. It is likely to say that these projects are more sensitive on confidentiality to keep their business secrets than all projects' groups in PRETDP.

Technology difference has positive relationship with intellectual project for core projects, while it showed negative moderating effect between age diversity and experimental output for all projects' group. So, how unique the project is matter for creating intellectual outputs of core projects, which could make a link to diversity in educational background. It could be inferred as the core projects in PRETDP is looking for more innovative ideas through diversified educational background and uniqueness in research subject.

Government investment and *private investment* also showed some differences. Government investment had a positive relationship for both intellectual and experimental output in all projects' group while it was not for core projects' group. This also could be linked with skill sharing behavior of all projects' group because more involvement of organizations leads to more spending in government fund. But, since it also showed the negative relationship with private investment, it is likely to say that more government research institutes, or universities are involved to achieve the benefit of skill sharing effect.

Based on the analysis on the direction of significant coefficients, the result on the analysis of hypothesis has been summarized as in Table 18. Only hypothesis on gender and age has been confirmed, while others are rejected due to lack of significancy in coefficients

Table 18. Summary of hypothesis test for intellectual output

Hypothesis	**Result**
For intellectual output	
H1. technology difference (core projects)	**Positive**
For experimental output	
H1-a. technology difference (all projects) x age diversity	**Negative**

* (Note) rest of hypothesis in H5 and H6 found to be not significant

5.6.2. The moderating effect of technology difference on R&D outcome

Table 19. Summary of findings on technology diversity and core projects on outcome

Variable	All Projects COM	All Projects EMP	Core Projects COM	Core Projects EMP	Direction of significant coefficient
	Confidence Interval of Estimated Coefficient (P-value) (%)				
Diversity in R&D Output					
Output diversity			NS		Similar
Diversity in Research Subject					
Technology Difference		NS	NS	NS	Different
Experimental Output x Technology Difference		NS	NS	NS	Different
Control – R&D Output Quantity					
Intellectual Output	NS		NS	NS	Different
Experimental Output	NS		NS	NS	Different
Control – R&D Output Quality					
Impact Factor average	NS		NS		Identical
SMART patent ratio	NS	NS		NS	Different
Inclusion of National Certification		NS	NS	NS	Different
Inclusion of Complete Prototype	NS	NS	NS	NS	-
Control – R&D Project					
Government investment (log)	NS		NS		Identical
Private investment (log)	NS			NS	Similar
Project duration			NS		Similar
Technical Readiness Level		NS		NS	Similar

* (Note 1) COM = commercialization; EMP = employment effect; NS = not significant
* (Note 2) Confidence Interval (positive) = 90%; = 95%; = 99%; = above 99%
Confidence Interval (negative) = 90%; = 95%; = 99%; = above 99%

Discussion on identical/similar factors Discussion points are those variables had identical or similar 'direction of significant coefficients' in Table 19. 'All projects' indicates inclusion of all 430 projects in PRETDP, while 'core projects' indicates those 100 projects have keywords of efficiency or cost reduction. Variables had identical or similar effect for both all projects and core projects are *output diversity, Impact Factor average, government* *investment, private investment, project duration,* and *technical readiness level.* The observations on these variables are already made in previous discussion section, so it seems unnecessary to have a redundant discussion.

Discussion on different factors These are critical points of this study that shows difference between all projects and core projects. These variables had difference 'direction of significant coefficients' in Table 19. *Technology difference* showed negative relationship with commercialization for all projects, while it showed no significant relationship with core projects' group. So, how unique the project is not only insignificant for project commercialization of all projects, but also it could have negative impact on commercialization outcome. Especially, technology difference negatively moderates the relationship between experimental output and technology difference. So, projects with more experimental output are more negatively affected by technology difference to achieve commercialization of all projects in PRETDP. This finding is exact opposite of findings in Chapter 3, where technology difference showed positive relationship with intellectual output of core projects' group. So, it is safe to say that technology difference is not a pursuit for general projects in PRETDP for better performance; but it is a critical factor for core projects to create more innovative outputs.

SMART patent ratio had significant impact on commercialization in core projects' group, while it shows significancy in all projects group. This could make an extension from findings in chapter 3. In chapter 3, it has been found how unique the project is matter for creating intellectual output, which was also derived from diversity in educational background and more professional quality in educational level. This is now link to relationship on patent quality and business success, meaning that creating technical difference from more diversified backgrounds and more educated team matters for commercialization of core projects in PRETDP. On the other hand, getting national certification matters for commercialization in RE all projects, meaning that RE R&D projects concentrate on securing evidence from public institution for safety issues. For example, if the photovoltaic model is to bel installed on water surface, it might require certification proves durability of the module or whether it does not release any toxic chemical substance in water. So, the quality of works for commercialization is different for all projects and core projects of PRETDP.

Based on the analysis on the direction of significant coefficients, the result on the analysis of hypothesis has been summarized as in **Table 20**. Only hypothesis on technology difference and its moderating effect on all projects group is confirmed

Table 20. Summary of hypothesis test for moderating effect of technology difference

Hypothesis	**Result**
For commercialization	
H2. technology difference (all projects)	**Negative**
H2-a. technology difference (all projects) x experimental output	**Negative**

* (Note) rest of hypothesis in H5 and H6 found to be not significant

5.7. Conclusion

Strategic R&D management has closely related to management of technology. Strategic R&D management is about figuring out how to do better portfolio management so discussion on different technologies [75] and core technologies [76] can strengthen its functionality. Although previous literatures have dealt with technology distance or core competency, but they did not have put together to find managerial insights, especially in public domain. This study expanded the discussion between technology difference and innovation performance [225,256] by adding analysis on outcome and also by applied this definition onto core projects in R&D portfolio management. This study redefined the relationship between input-to-output and output-to-outcome relationship of Public Renewable Energy Technology Development Program (PRETDP) by using technology difference as a moderating variable and by making comparison between all projects' and core projects' group.

This study found that there are similarities between all projects and core projects in PRETDP: gender diversity is positively related with both outputs in both groups, while age diversity is negatively related with them. Also, more previous experience in PRETDP program and more participation from industry could be helpful for more experimental output. Output diversity has influence on commercialization and employment effects of all projects, and it also made influence on employment effects of core projects' group. Impact Factor average has shown negative relationship with employment effect for both groups which may have been caused by requirement of firms' participation in research consortium. Project duration is negatively influenced on employment effect, indicating that delay in projects is not just bad for outputs but also affect the outcome of projects in PRETDP.

On the other hand, both groups are found to have differences. Their difference was found in educational background and educational level; core projects needed researchers with more diversified majors but with more advancement degree than all projects' group. Also, heterogeneous collaboration with larger consortium size and more researchers are needed for all projects' group, while core projects tend to keep the information onto inner circle with small number of researchers. Technology difference was found to have impact on core projects' intellectual performance; combining with more educational background diversity, it is reasonable to think that more innovative ideas are important for core projects' group. Meanwhile, all projects' group tend to show skill sharing behaviors of inclusion of more institutions, researchers, and more government investment – especially, inclusion of non-profit organization given the negative relationship to private investment. Their difference was also found in output quality; all projects' group was positively affected by inclusion of national certification, while core projects' group was more affected by SMART patent ratio. Also, technology difference showed negative relationship with commercialization for all projects, while it showed no significant relationship with core projects' group. So, how unique the project is not only insignificant for project commercialization of all projects, but also it could have negative impact on commercialization outcome. Output diversity has a positive impact on outcome for both all projects' group and core projects' group, especially for employment effect. Having diversity in outputs means more tasks to fulfill in the research work, so more human resources will be required to do the work. Although output diversity can help the commercialization of all projects' group, it does not find to have significant effect for commercialization of core projects' group. So, it comes to managerial decision whether to promote output diversity for core projects' group by weighing the importance of promotion of employment effect

Difference in output quality is a significant finding from this study; all projects' group are more affected by inclusion of national certification for commercialization, while core projects' group has closer relationship to SMART patent ratio. From managerial perspective, how well-organized the project is important to discrete projects with possibilities in commercialization for all projects' group. Technology difference should not be major concern for all projects' group. However, technology difference matters for core projects' group because how unique the technology is matters for commercialization. The SMART patent ratio shows that core project's group require patents with more quality. Therefore, it could be quite distinguishable how managerial practice should be different in terms of output quality. Quality of academic publication was not significant for promoting employment effects of both all projects' group and core project's group. So, managers must decide whether to value quality in academic output or to value alignment of policy.

The findings of this study highlight the relationship between diversity and R&D performance, which could be used in the public R&D managerial sector. By pioneering on the relationship between input-to-output and output-to-outcome, it could open new research stream on performance measurement and diversity study and could enrich the managerial implications to strategic management of PRETDP. By providing added information to policymakers, this study could contribute to the improvement of the public renewable energy R&D managerial system in South Korea.

Chapter 6. Conclusion

6.1. Summary

Adoption of strategic R&D management in public R&D sector is necessary for improvements in R&D performance and efficiency. Public Renewable Energy Technology Development Program (PRETDP) has been experiencing fast growth in public R&D expenditure, so now is a right time for tracking back on previous expenditures to make investments in the future to be more efficient. From the perspective of resource-based view, diversity in R&D team and output can be considered as valuable resources of PRETDP that should be scrutinized and used strategically to enhance program's overall performance. Also, considering characteristics of research activities in PRETDP, technology difference and core competencies can play effective roles to inform R&D managers about differences in managerial points of projects in PRETDP. By thorough investigations on these factors, managers of PRETDP could receive valuable information to make strategic decisions.

The first essay was focused on input diversity of R&D team to investigate how those diversity affect outputs of PRETDP. This article considered R&D team diversity in two aspects: one for demography and another for collaboration. As a result, this study found that demographic diversity of R&D teams in PRETDP can have impacts on performance at both directions. For demographic diversity, age diversity works negatively for both intellectual and experimental output, but other demographic diversity variables acted in various direction (e.g., gender, education background, and educational level). This study also found that heterogeneous collaboration with larger consortium size and more researchers can have a positive impact on experimental output.

Second essay was designed to find relationships between R&D output diversity and outcome of PRETDP. This article considered output diversity as well as output quantity and quality. For outcome, commercialization and employment effect were considered. This essay found that output diversity is a common influence factor for positivity in commercialization and employment effects. However, there were many differences. Impact Factor average has shown negative relationship with employment effect, which may have been caused by requirement of firms' participation in research consortium. Inclusion of national certification only affected commercialization, meaning that credibility of projects' is crucial factor for commercialization of PRETDP in general. Therefore, earning public certification is more crucial factor for commercialization of PRETDP projects.

Third essay was designed to provide strategic R&D management insights for PRETDP by adding discussion on technology difference and core projects' management from previous two essays. Based on same research model of previous two essays, this article added technology difference as a moderating variable to observe interaction between technology difference and diversity variables. Also, this article extracted core projects' group from PRETDP to observe difference between all projects' group and core projects' group in terms of diversity and technology difference. This essay found that there exists major difference between all projects' group and core projects' group in terms of output quality; all projects' group was positively affected by inclusion of national certification, while core projects' group was more affected by SMART patent ratio. Also, technology difference showed negative relationship with commercialization for all projects, while it showed no significant relationship with core projects' group. Therefore, quality of patent is important for core projects while earning certification is more important for all projects' group. This article should provide overall implications for both groups that could be applied to reform project evaluation process and objective management.

The implementation of strategic R&D management can be started from the analysis of accumulated data. By turning random data into meaningful information, R&D managers can have more insights to make strategical decision. PRETDP has been receiving uniformized assessment as rest of energy technology development program. It did not have strategic managerial plan for its core projects management, either. Findings in these studies can provide valuable information to managerial institution of PRETDP to think about the change in their managerial practice.

6.2. Contribution

These three studies have few academic implications. First, they could be one of pioneering studies for the managerial practice of output diversity in public R&D. Although there might be several studies referring to input diversity and innovative performance, there are not many studies connecting input diversity with various outputs and outcomes. Second, these studies have approached core competency and technology difference in the perspective of R&D performance to develop strategic management plan. Previous literatures have dealt with technology distance or core competency as a motive of collaboration, but they did not have put together to find managerial insights, especially in public domain. This study specifically targeted for renewable energy R&D program so that practical insights could be applied to managerial decisions. Third, these studies showed that diversity in public renewable energy R&D could be treated as resources and does not need to appeal on fairness for the promotion of diversity in research communities. As pointed out earlier in chapter 2, most of previous study made argument based on the ground of fairness. However, this study showed how each diversity affect the performance, both positively and negatively, so that it provides the evidence what type of diversity should be promoted and controlled. Fourth, this study made discussion of strategic management in renewable energy R&D domain. As IRENA has published report on *gender perspective* recently, demographic diversity starts becoming important in renewable energy field as it seeks for public acceptance to accelerate deployment. However, such discussions are not active enough as many studies had dealt with demographic diversity in IT or bio industry where technology changes fast. From this perspective, discussions provided in this study can satisfy growing interest of diversity in renewable energy field.

Political implications can also be found in this study. First, this study can help PRETDP to develop strategic management plans that could not only support higher R&D basic plans but also provide feedbacks to them. As *Science and Technology Basic Plan* demands research environment that could nurture disruptive innovation, this study tells how diverse configuration of R&D teams can affect the renewable energy R&D performance. As this study showed that organizing R&D team with balanced gender and natural science major prove to be positive for renewable energy R&D performance, it would be desirable for higher plan to reflect this finding for renewable energy technology development and to verify if such findings continue other R&D fields as well.

Second, this study can improve portfolio management techniques for PRETDP. The improvement in managerial practice of PRETDP could make this public resource to be used better, and more importantly, this insight can help acceleration renewable energy deployment in long run. So, it would be desirable for PRETDP to have differentiate systems for project evaluation and management in terms of core competency. One way to apply this would be creating different versions of project proposal form or changing weight in project evaluation criteria for core projects. There are multiple criteria for evaluation such as technical competency, R&D team competency, human resource use, or commercial accomplishments. So, core competency projects should be more credited for technical competency in terms of project's challenge and creativity, while general renewable energy projects should be more credited for efforts for commercialization. Another way would be using various variables used in this study to diversify portfolio in various perspectives. By using technology difference and political priority, PRETDP can predict where to focus its managerial resources to make the best accomplishment. Third, this study can contribute to the development of performance evaluation index for renewable energy in long term. This study may have opened discussion points to develop performance index for PRETDP. If findings in this study can be applied in practice and make modification through several trials, it would be possible to provide objectified index for renewable energy R&D projects so that R&D management agency would be less affected by change in personnel and rather function as a reliable managerial system.

6.3. Limitation and future research

Although this study has dealt with strategic R&D management at multiple level, there are certain limitations and many more to study in the future. Especially, the subject for demographic diversity could be different by countries so that there are much more to be explored yet.

The limitation of this study is that regional characteristics could affect the results of our study. Although study on output could be exceptional to this, R&D team diversity and collaboration diversity are specifically focused on regional variables. Also, this study only used case of South Korea only. Although this study covered inputs and control variables treated in other R&D environments, other regions may require specified variables reflecting characteristics of their research program to generalize our findings to the extent of a universal phenomenon. Also, every country has different energy mix and different point of view on renewable energy so that it would need further discussion to be applied in other region.

There were some restrictions with data usage as well. Although this study tried to take full advantage on the possessed data, there was certain restriction on data analysis due to not enough samples in certain group. For instance, collaboration diversity would have used more detailed categories for analysis if interactive terms on collaboration types were included, but some of these sub-categories created by interactive terms did not have enough observations for regression analysis. This study dealt with 430 samples, so if more data sample is collected in the future, more scrutinized analysis can be conducted.

This study wants to suggest a couple of ideas for future studies. First, it would be interesting to compare cases with other countries to verify if findings in this study could be applied to other regions as well. It would be even better if case study can be conducted based on economic status of countries, such as developed country and developing country. Second, it could be also interesting to see if managerial diversity contributes to success of the project. Public sector in South Korea frequently confronts many changes in personnel and change in political direction. Since this study has dealt with research projects, it would be interesting to analyze whether managerial side contributes to the project success. Third, it would be interesting to see how input diversity affect the output diversity, and if there exist mediated effect on output diversity in the context of input to outcome relationship.

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Appendix

Appendix 1. Table of correlation test result

No	Variable name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Independent Variables																										
1	Intellectual Output (log)	1.00																								
2	Experimental Output (log)	0.01	1.00																							
3	Commercialization	-0.00	0.33**	1.00																						
4	Employment Effect	0.07	0.40**	0.32	1.00																					
R&D Team Diversity – Demography																										
5	Gender	0.23**	-0.16**	-0.16**	-0.13**	1.00																				
6	Age	-0.37**	0.24**	0.17**	0.15**	-0.17**	1.00																			
7	Education background	0.04	0.02	-0.04	0.09	0.30**	0.07	1.00																		
8	Education level	0.24**	-0.05	-0.05	0.01	0.15**	0.00	0.04	1.00																	
R&D Team Diversity – Collaboration																										
9	Homogeneous collaboration	0.23**	-0.26**	-0.18**	-0.16**	0.25**	-0.30**	0.13**	0.14**	1.00																
10	Heterogeneous collaboration	-0.10*	0.39**	0.25**	0.26**	-0.18**	0.43**	-0.15**	0.05	-0.70**	1.00															
11	Non-collaboration (baseline)	-0.13**	-0.23**	-0.13**	-0.17**	-0.04	-0.24**	0.05	-0.22**	-0.20**	-0.57**	1.00														
R&D Output Diversity																										
12	Output Diversity	0.30**	0.67**	0.32**	0.35**	-0.03	0.09	-0.02	0.09	-0.15**	0.33**	-0.28**	1.00													
Research Project Diversity																										
13	Technology Difference	-0.03	0.00	-0.09	-0.03	-0.01	0.06	-0.04	0.03	-0.03	0.02	0.01	0.02	1.00												
Control – R&D Output Quality																										
14	Impact Factor average	0.54**	-0.12*	-0.04	-0.16**	0.28**	-0.33**	0.04	0.16**	0.21**	-0.14**	-0.05	0.18**	-0.05	1.00											
15	SMART patent ratio	0.29**	0.06	0.04	0.06	0.06	-0.04	-0.04	0.17**	0.03	0.04	-0.09	0.43**	0.03	0.17**	1.00										
16	Inclusion of National Certification	-0.08	0.34**	0.29**	0.16**	-0.17**	0.08	-0.00**	-0.11*	-0.06	0.08	-0.05	0.29**	-0.11*	-0.07	-0.01	1.00									
17	Inclusion of Complete Prototype	-0.07	0.52**	0.26**	0.28**	-0.14**	0.20**	-0.06	-0.13**	-0.28**	0.31**	-0.10*	0.39**	0.00	-0.21**	0.00	0.22**	1.00								
Control – R&D Team																										
18	Consortium size (log)	0.22**	-0.02	-0.02	-0.01	0.07	-0.16**	-0.04	0.09	0.02	-0.04	0.02	0.09	0.00	0.10*	0.10*	0.02	-0.01	1.00							
19	Participants from industry	-0.36**	0.43**	0.31**	0.31**	-0.22**	0.48**	0.02	-0.30**	-0.46**	0.41**	-0.03	0.20**	0.01	-0.39**	-0.05	0.21**	0.34**	-0.11*	1.00						
20	Leader’s experience in RE R&D	0.30**	0.39**	0.17**	0.26**	-0.01	0.17**	0.02	0.22**	-0.10*	0.37**	-0.39**	0.37**	-0.05	0.09	0.18**	0.14**	0.17**	0.11*	0.11*	1.00					
21	Number of researchers (log)	0.49**	0.28**	0.09	0.23**	-0.02	0.01	0.01	0.28**	-0.02	0.32**	-0.41**	0.36**	-0.07	0.23**	0.19**	0.11*	0.07	0.10*	-0.06**	0.67**	1.00				
Control – R&D Project																										
22	Government investment (log)	0.39**	0.35**	0.16**	0.29**	-0.09	0.17**	0.06	0.19**	-0.07	0.38**	-0.43**	0.36**	-0.06	0.14**	0.15**	0.11*	0.12*	0.09	0.05	0.68**	0.84**	1.00			
23	Private investment (log)	0.05	0.48**	0.27**	0.37**	-0.23**	0.42**	-0.02	0.02	-0.46**	0.66**	-0.38**	0.38**	-0.01	-0.11*	0.07	0.15**	0.29**	-0.01	0.50**	0.58**	0.60**	0.75**	1.00		
24	Project duration	0.17**	0.04	-0.04	-0.01	-0.02	-0.04	-0.01	0.13**	0.04	0.13**	-0.22**	0.15**	-0.02	0.15**	0.07	0.09	-0.01	0.17**	-0.11*	0.31**	0.39**	0.51**	0.33**	1.00	
25	Technical Readiness Level	-0.13**	0.33**	0.38**	0.21**	-0.07	0.31**	-0.08	-0.03	-0.34**	0.44**	-0.21**	0.29**	0.03	-0.18**	0.00	0.15**	0.26**	-0.04**	0.44**	0.21**	0.11*	0.13**	0.39**	-0.03	1.00

Note: $* p < 0.05$; $** p < 0.01$

Appendix 2. Summary of literature review on demographic diversity (1)

Author	Year	Objectives	Scope	Variables	Result	Discussion
Mothe et al.	2021	age diversity → tech. Innovation	Luxembourg, private firms (2010-2012)	(DV) product or process innovation (0 or 1) (IV) age polarization, age variety (Blau's index) (CV) firm size, firm age, part-time, R&D department, number of competitors, collaboration, quality mgmt.	▪ variety age groups → (+) ▪ polarized age groups → (−)	▪ Information sharing alleviates age polarization effect ▪ No single applicable theory of corporate age structure ▪ (Further study) organizational culture, leadership, etc.
Xie et al.	2020	gender diversity → innovation efficiency	China, Annual Census of Industrial Enterprises (2009-2013)	(DV) percentage of the firm's new product sales out of the total sales (IV) gender diversity (CV) return of sales, firm age, firm size, export intensity, male-dominated industry, R&D team size (MV) task intensity, task complexity, market competition, market uncertainty	▪ gender diversity → (+) ▪ enhanced when task intensity or complexity is high	▪ provide evidence for how mixed-gender R&D teams work and help in improving innovation ▪ Firms should pay attention to the gender composition of team ▪ (Limitation) only Chinese firms, neglect inverted-U possibility
Kou et al.	2019	gender diversity → R&D efficiency	China, statistical yearbook on Science & Technology (2009-2017)	(DV) R&D efficiency score (papers, books, patents, and standards) (IV) gender diversity (CV) GDP per person, education investment per person, R&D labor input, R&D capital input, basic & applied research personnel	▪ more male → (+) ▪ (for papers, books only) more female → (+)	▪ gender gap exist in performance ▪ different types of project should adopt different gender ratio ▪ (Limitation) did not include R&D stage as control variable
Martinez et al.	2017	gender, education, skill diversity → innovation performance	Spain, Technological Innovation Panel (2003)	(DV) incremental, radical innovation (IV) gender, education, skill diversity (Blau's index) (CV) firm size, R&D team size, innovation intensity, technology intensity, year effects	▪ diversity in R&D team (particularly, education diversity) → (+) radical innovation	▪ Provide insights to R&D managers ▪ (Limitation) did not control the formation of the team ▪ (Further study) interactions with top management in process
Valls et al.	2016	educational diversity → team performance	Spanish bank branch (2002-2003)	(DV) team performance (managers' evaluation) (IV) educational diversity (Blau's index) (CV) educational level, team size, team tenure (MV) team climate (member's opinion on team)	▪ educational diversity x team climate → (+)	▪ Educational diversity can work in bi-direction (Knippenberg, 2004) ▪ Team manager should foster better team climate ▪ (Further study) larger-scale

Note: DV = Dependent Variable; IV = Independent Variable; CV = Control Variable; MV = Moderating Variable

Appendix 3. Summary of literature review on demographic diversity (2)

Author	Year	Objectives	Scope	Variables	Result	Discussion
Subramanian et al.	2016	educational level → Innovation performance	Singapore, A*STAR (2004-2008)	(DV) innovation performance (number of patents) (IV) technological diversity, educational level diversity, educational level similarity (CV) gender, nationality, government R&D funding, firm size, R&D intensity	when technological domains are heterogeneous, ▪ similar educ. level → (+) ▪ diverse educ. level → (−)	▪ Firm need to weigh the costs & benefits of workforce diversity ▪ Firms need to value their R&D staff with basic skills ▪ (Limitation) organizational culture was not considered
Han. S. Y.	2015	R&D personnel diversity → firm performance	S. Korea, MSIT (2004-2007)	(DV) firm's sale, ROA (IV) gender, age, major, education level (Blau's index) (CV) government investment, export, number of employees, firm age, capital adequacy ratio	In high & medium high tech, ▪ gender diversity → (+) ▪ age diversity → (−) ▪ major diversity → (+)	▪ provide insight for firm's strategy ▪ (Limitation) R&D sales R&D team performance, so that R&D output should have added as CV
Østergaard et al.	2011	employee diversity → firm's innovation	Denmark, DISKO4 (2003-2005)	(DV) firm innovation (whether firm introduced new product or not) (IV) gender, age, ethnicity, education diversity (CV) organizational change, collaboration with external partners, firm industry, firm size, firm age	▪ education & gender → (+) ▪ age → (−) ▪ ethnicity → NS	▪ Diversity cannot be ignored in relation to a firm's innovation ▪ (Limitation) cross-sectional analysis ▪ (Further study) should consider mgmt. culture
Liang et al.	2007	demographic diversity → team performance	Taiwan, information technology (2005)	(DV) performance efficiency of software (IV) knowledge diversity (education background, level, work department), social (gender, age), value (member's opinion)	▪ knowledge diversity → (+) ▪ value diversity → (−)	▪ Provide information for managers to form software team ▪ (Limitation) some of variables are too objective
Reagans et al.	2001	diversity network (educational level) → team productivity	automotive, chemicals, electronics, aerospace, pharmaceuticals, biotechnology, oil (1985-1986)	(DV) team productivity (proposal, report, book, patent) (IV) educational diversity network density, network heterogeneity (CV) task, competition, R&D team size, R&D stage	▪ network density → (+) ▪ network heterogeneity → (+)	▪ Interchange of skills, experience are important for productivity ▪ Greater network heterogeneity may reduce other outcomes other than productivity ▪ (Limitation) does not explain the origin of diversity

Note: DV = Dependent Variable; IV = Independent Variable; CV = Control Variable; MV = Moderating Variable

Appendix 4. Summary of literature review on collaboration diversity

Author	Year	Objectives	Scope	Variables	Result	Discussion
Zhang et al.	2018	partner diversity → Innovation performance	Global, DII (USPTO, EPO, JPO, SIPO, and more) (2007-2016)	(DV) number of patents (IV) collabo. diversity (firms, universities, gov. institutes) (MV) technological diversification (CV) pre-sample patents, inventors, R&D age, number of partners, organizational type (univ or gov.), geographical region (Asia, Europe, etc.)	▪ collaboration diversity → (+) ▪ focal organization's knowledge → (+) moderate	▪ collaboration diversity offers both scientific & industrial production ▪ focal organization has more opportunity to exploit knowledge ▪ (Further study) also, academic publication should be considered
Beck et al.	2014	cooperation diversity → innovative product	Switzerland, Swiss Economic Institute (1999-2008)	(DV) sales of new products (IV) diverse types of partners (customer, supplier, competitors) (CV) number of external partners, exports ratio, technology level, firm size	▪ diversified coop. → (+) ▪ however, benefit of diversification decreases after certain point	▪ Improve managerial decision by providing strategic management ▪ (Limitation) did not consider national origin ▪ (Further study) identify better mechanism for collaboration with large enterprise
van Beers et al.	2014	cooperation diversity → innovation performance	Netherlands, IT (1994-2006)	(DV) sales of products (radical, incremental) (IV) partner diversity (prior experience, sector, size) (CV) R&D intensity, training, sector, process, and organizational innovation	▪ functional diversity → (+) radical sales ▪ geographical diversity → (+) incremental sales	▪ deeper understanding on partner diversity ▪ (Limitation) more characteristics of partners (Power position, etc.) ▪ (Further study) sector specific analysis
Raesfeld et al.	2012	partner diversity → public R&D outcome	Netherlands, Nanotechnology (1992-2009)	(DV) application development degree (1 as prematurely terminated and 4 as well-developed) (IV) technological diversity (patent class), project's partner type (company, gov., academic, university) (CV) network centrality, number of partners	▪ collaboration with different partners → (+) ▪ technological diversity → U-shape effect	▪ Performance was measured five years after completion ▪ (Limitation) resource complementarity (only suitable for private sector study)
Kang et al.	2010	partner type → product innovation	S. Korea, STEPI & KIS (2003)	(DV) product innovation (firm's sale) (IV) perception scale on collaboration (1 = not useful and 5 = very useful), collaboration partner (competitor, customer, supplier, university) (CV) R&D intensity, firm size, start-up, market size	▪ R&D collaboration with customer & university → (+) ▪ R&D collaboration with competitor & supplier → (−)	▪ provide additional evidence on conflicting results ▪ high-tech firms more positively collaborate with competitors ▪ (Limitation) need better variable to suit its research purpose

Note: DV = Dependent Variable; IV = Independent Variable; CV = Control Variable; MV = Moderating Variable

Appendix 5. Summary of literature review on output diversity

Author	Year	Objectives	Scope	Variables	Result	Discussion
Altaf et al.	2015	product diversity → firm performance	India, ProwessIQ (2010-2014)	(DV) return on assets (IV) product diversity (share of firms, number of product lines) (CV) company size, advertisement intensity, firm leverage	▪ product diversity → (−)	▪ optimal level of product diversification is needed ▪ (Limitation) used data for product diversity is subjective
Lee et al.	2011	financial performance indicator diversity → organizational performance	S. Korea, survey (top 200 manufacturing company) (2006)	(DV) organizational performance (scale opinion, comparing to previous fiscal year) (IV) number of financial performance indicators (CV) existence of performance measurement system, number of non-financial performance indicators	▪ performance measurement system → (+) ▪ diversity in financial performance indicators → (+)	▪ Managers should develop diversified performance indicator ▪ Diversified indicators increase interaction b/w members ▪ (Limitation) only appliable to top 200 companies in S. Korea
Sukpanich et al.	2007	product diversity → firm performance	Fortune Global 500 (1997-2003)	(DV) return on sales (IV) product diversity (ratio of product sales group) (CV) firm asset, administrative expenses	▪ product diversity → inverted-U shape	▪ The effect of product diversity strategy depends on its level of intra-regional sales ▪ (Limitation) operational performance was not considered ▪ (Further study) strategic decision in regional dimension
Lin et al.	2006	patent portfolio diversity → firm value	USA, USPTO (1985-1999)	(DV) return on sales (IV) broad tech diversity, core tech diversity (weighted based on density of patent population) (CV) firm size, average claims, originality, R&D intensity, average self-citation ratio	For focal firm has high profitability ▪ broad technology diversity → (+) For focal firm above average, ▪ core field diversity → (+)	▪ technology portfolio strategy has profound effect on business ▪ (Further study) research on technology portfolios and R&D strategy
Tallman et al.	1996	product diversity → firm performance	U.S. Multinational manufacturing firms (1987)	(DV) return of sales (IV) product diversity (ratio of product sales group) (CV) firm size, leverage, industry growth	▪ product diversity → inverted-U shape	▪ Excess product diversification may harm performance ▪ (Limitation) excluded studies on small firms

Note: DV = Dependent Variable; IV = Independent Variable; CV = Control Variable; MV = Moderating Variable

Appendix 6. Summary of literature review on output quantity and quality

Author	Year	Objectives	Scope	Variables	Result	Discussion
Cho et al.	2017	comparison of SCI quality index	S. Korea, Government R&D (2015)	(Method) apply different quality index on government R&D projects (Analysis) biochemistry, electronics, material science, pharmacy	▪ mrnIF or R2nIF > average impact factor	▪ mrnIF or R2nIF would be best suitable for overly dispersed effect of R&D performance ▪ However, if researcher works in same technology field, it may be applicable to show trends
Baek et al.	2016	R&D input → SMART patent index	S. Korea, Government Research Institution (2013-2015)	(DV) patent counts, SMART patent index (IV) full time and Part time employee, government investment (MV) technology type (basic, application)	Unlike quantity in patent, SMART patents are ▪ Public R&D Fund → (−) SMART ▪ Basic Research → (+) SMART	▪ GRI rely too much on patent count, rather than quality ▪ public funded R&D evaluation must reflect better on quality ▪ (Further study) organizational culture, leadership
Park. W. J.	2015	tech. compatibility → commercialization	S. Korea, Survey on Government Research Institute (2013)	(DV) commercialization (sales, creation of prototype) (IV) compatibility with previous technology (CV) R&D personnel size, Inclusion of firm, technology level of previous product	▪ compatibility with previous technology → (+)	▪ Increase in TRL may have side effect on commercialization ▪ (Limitation) did not consider characteristics of firm industry ▪ (Further study) more consideration on joint-research
Lee et al.	2012	patent & certification → firm's ROI	S. Korea, Technology innovation program for SME (2006-2008)	(DV) return on investment (ROI) (IV) patent and certification counts (CV) public fund amount, duration, project type, R&D personnel ratio, firm age, technology field, collaboration type	▪ patent & certification application → (+)	▪ Although certification may take more time in acquirement, it is an important output ▪ chemistry or electronics has better ROI than bio-medical ▪ (Further study) industry specific analysis on bio-medical

Note: DV = Dependent Variable; IV = Independent Variable; CV = Control Variable; MV = Moderating Variable

국문 초록

본 졸업논문에서는 한국 정부가 신재생에너지핵심기술개발 사업을 보다 전략적으로 관리할 수 있는 방안에 대하여 다루고 있다. 본 논문은 해당 분야에 자원기반관점(RBV)을 적용해 그 동안 관리 요인으로 고려되지 않았던 투입물과 산출물을 자원으로써 관리할 필요가 있음을 주장하고자 한다. 본 논문은 연구팀과 컨소시엄의 다양성과 산출물의 다양성이 성과에 미치는 영향을 분석하고, 여기에 기술적 차별성과 핵심과제 군을 활용한 전략적 관리 방안을 제시함으로써 정책결정자의 의사결정에 필요한 정보를 제공하고자 한다. 국내 신재생에너지핵심기술개발사업은 연간 2,000억 이상 투자되는 규모가 매우 큰 사업이다. 특히 최근 전 세계적으로 신재생에너지기술개발 투자가 늘어나는 흐름에 따라, 국내사업도 예산 비중이 더욱 늘어나고 있어 현 시점에서 본 연구의 결과가 향후 예산 집행의 효율성 향상에 도움을 줄 수 있을 것으로 판단한다.

본 논문은 세 개의 세부 연구로 구성되어 있다. 첫 번째 연구에서는 연구개발 컨소시엄 내의 인구학 및 협력 다양성이 기술개발 산출물에 어떠한 영향을 미치는지에 대해 중점적으로 분석하였다. 종속변수로는 지적 및 실험 산출물을 활용했고, 분석 방법은 위계적 회귀분석을 사용했다. 2009년부터 2015년 사이에 신재생에너지핵심기술개발사업에서 종료된 과제에 대해 분석한 결과, 여러가지 전략적 관리방안이 도출되었다. 인구학적 다양성은 나이의 경우 일관적으로 부정적인 영향을 보였으나, 그 외에는 양방향으로 영향을 미치는 것으로 나타났으며 이질적 협력은 결과에 긍정적이었다.

두 번째 연구에서는 산출물의 다양성이 결과물에 미치는 영향에 대해 분석해 보았다. 또한, 산출물의 다양성 외에 산출물의 양적 요소와 질적 요소가 결과물에 미치는 영향에 대해서도 분석하였다. 종속변수로는 사업화 여부와

고용 효과를 사용하였으며, 분석 방법으로는 위계적 회귀분석을 사용했다. 신재생에너지핵심기술개발사업에서 2009년부터 2015년 사이에 종료된 과제에 대해 분석한 결과, 산출물의 다양성은 사업화와 고용 효과에 영향을 미치는 것으로 보았다. 또한, 핵심과제 군의 경우 특허의 질적 요인이 사업화에 중요한 영향을 미쳤으나, 전체과제 군에서는 국가인증의 확보가 더욱 중요한 것으로 나타났다.

세 번째 연구에서는 앞서 두 개에서 분석한 연구모델에 대하여 기술적 차별성과 핵심과제에 대한 논의를 더하여 신재생에너지핵심기술개발사업의 대한 전략적 관리 방안에 대하여 포괄적으로 기술하였다. 본 연구에서는 앞서 연구의 변수들의 분석 모형에 기술의 차별성을 조절변수로 더하였으며, 핵심과제 군을 별도로 분류하여 회귀분석 결과의 차이가 있는지 확인하였다. 마찬가지로 2009년부터 2015년 사이에 종료된 과제에 대해 분석한 결과, 기술적 차별성은 핵심과제 군과 전체과제 군에 다른 영향을 미치는 것으로 나타났다. 특히, 핵심과제 군의 경우, 특허의 질적 요소에 대한 논의와 더해져, 기술적 차별성이 성과에 중요한 영향을 미치는 것으로 나타났다.

분석 결과를 종합하면 신재생에너지핵심기술개발에서 전체과제 군과 핵심과제 군은 기술적 차별성에 대한 중요도가 다름을 알 수 있다. 또한, 다양성의 경우 전반적으로 중요하지만, 인구학적 다양성 요소의 경우 긍정적인 요소와 부정적인 요소가 나뉘므로, 무분별한 다양성의 조성은 권장되지 않는다. 전략적 R&D 관리방안은 주어진 데이터를 여러 관점에서 분석하고, 이를 통해 시사점을 도출하는 것으로부터 시작한다고 할 수 있다. 현재 국내 신재생에너지기술개발사업은 다른 에너지기술개발사업과 분리된 특성의 평가제도가 시행되고 있지 않기 때문에, 사업의 성과제고와 관리기관의 전문성 제고를 위해 더 다양한 전략적 사업관리 방안이 제시될 필요가 있다. 이와 같은 관점에서 본 졸업논문은 공공분야 R&D 관리자와 정책결정자들에게 유용한

정보를 제공할 수 있으며, 이는 다양성의 관리 실무체계 향상에도 활용될 수 있을 것으로 기대된다.