Commercialization

of Environmental Technology

by Small and Medium Enterprises

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COMMERCIALIZATION OF ENVIRONMENTAL TECHNOLOGY BY SMALL AND MEDIUM SIZED ENTERPRISES

COMMERCIALISERING VAN MILIEUTECHNOLOGIE DOOR HET MIDDEN- EN KLEINBEDRIJF

Thesis

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Summary

In addition to sustainable development, interest in environmental technology is continuing. According to the German Greentech report, the world market for major environmental technologies (e.g. sustainable water management, waste management and recycling, and material efficiency) represented €1,298 billion EUR in 2016 and is expected to reach €2,259 billion EUR by 2025. Following this trend, the budget for the commercial-R&D program in the South Korean environment sector expands annually. In 2018, the Ministry of Environment provided $129 million USD in R&D projects for the application and development phase. However, the commercialization success rate – defined as market introduction and new sales generation – of commercial-R&D programs supported by the government—in the environment sector— is very low compared to other developed countries.

The government's efforts to promote the commercialization of private sector technologies—R&D subsidies, initial commercialization support— are focused on estimated market volume. Also, the importance of technology (e.g. the technological gap between Korea and developed countries) is emphasized. As new product development is a complex process, the government needs a comprehensive understanding of the commercialization of environmental technologies by SMEs.

So far, environmental innovation has mainly been studied from a perspective of diffusion of innovation to create demand (Coenen & Klein-Vielhauer, 1997; Baas, 2007, Montalvo & Kemp, 2008; Horbach et al., 2012). However, although incremental environmental innovation has already been invented or applied by many companies (Cleff & Rennings, 1999), few attempts have been made to comprehensively understand the successful commercialization of new environmental technologies in terms of technology providers.

Through this study, the author provides insight into the commercialization of environmental technology by SMEs. More specifically, it provides a comprehensive understanding of the key factors and the mechanisms[1] that influence the commercializing environmental technologies. In this thesis "environmental technologies" refers to end-of-pipe and eco-friendly process technologies. The theoretical basis of this study is based on a

1 In this thesis, mechanism refers to the interrelation of factors.

framework for the new product development literature and empirical evidence. To consider the characteristics of environmental technology, the framework includes the determinants of eco-innovation.

This thesis applied a convergent parallel mixed-method design (Creswell & Clark, 2011; Tashakkori & Teddlie, 1998). Convergent parallel design (Creswell & Clark, 2011; Tashakkori & Teddlie, 1998) improves the validity of the research results by simultaneously performing statistical-quantitative research and qualitative research, and comparing and contrasting each result. At the same time, quantitative and qualitative studies conducted on the same case complemented the identification of success factors. Qualitative studies have provided an understanding of the dynamics and correlations of success factors.

This research proposes 12 success factors in SMEs' environmental technology commercialization and suggests mechanisms for scaling. The 12 factors include five key factors ("technology superiority," "technology reliability," "market research skills," "competitive intensity," and "competitive positioning") and seven secondary factors ("technological synergy," "broad application," "good technical service," "top management commitment and support," "downstream alliance partnership," "environmental regulation," and "government support policy"). Based on the findings of this study, the author proposed a preliminary model for commercialization of environmental technologies. The model classifies the factors into four clusters: technology, market, organization, and environment[2], and shows the interrelationships between the factors. In the process of developing environmental technologies, organization-related and environment-related factors (i.e. government support policies such as R&D subsidies) contribute to improving the superiority and reliability of technology. Organization-related factors include top management commitment and support, market research skills, and technological synergy. Environmental technology with superiority and reliability supports the factors that have a positive influence on commercialization—diversification of technology application, technology service, downstream partnership with large companies, and competitive positioning— in the marketing process. The competitive intensity and environmental regulation in the target market can be a positive factor in their own right. This model is a first attempt to comprehensively understand which factors contribute to

[2] In this thesis, the term 'environment' used as a classification of factors influencing commercialization refers to social environments such as policies and regulations for market context.

environmental technology commercialization from the technology provider's perspective.

This study contributes to literature and practice: first, the result of this study adds environmental technology as a specific sub-field to existing research areas on technology commercialization. Second, this study potentially contributes to the efficient operation of the government's SME commercialization promotion policy by providing policymakers with insights into the environmental technology commercialization.

Samenvatting

Naast duurzame ontwikkeling blijft ook de belangstelling voor milieutechnologie toenemen. Volgens het Duitse Greentech rapport was het marktvolume voor de belangrijke milieutechnologieën (zoals duurzaam waterbeheer, recycling en efficiënt materiaalgebruik) 1.298 miljard Euro in 2016. Naar verwachting loopt dit op naar 2.259 miljard Euro in 2025. Het budget voor het R&D programma van de Zuid-Koreaanse milieusector neemt evenredig toe met deze trend. In 2018 zette het Ministerie van Milieu 129 miljoen US$ voor R&D ter ontwikkeling en toepassing van milieutechnologie. De succesvolle commercialisering – gedefinieerd als marktintroductie en nieuwe verkopen -- daarvan blijft in Zuid-Korea echter achter in vergelijking met andere ontwikkelde economieën.

De inspanningen van de overheid om de commercialisering van milieutechnologie in de particuliere sector te bevorderen – door subsidies en de ondersteuning van marktintroductie – zijn gericht op een geschat marktvolume. Nieuwe technologie, en bijvoorbeeld de technologische achterstand van Zuid-Korea op ontwikkelde landen, is daarbij van groot belang. De ontwikkeling van nieuwe producten is een ingewikkeld proces. Daarom wil de overheid het proces van het commercialiseren van milieutechnologie door het MKB goed leren begrijpen.

Tot nu toe is milieu-innovatie vooral onderzocht vanuit een perspectief van innovatie-diffusie (Conen & Klein-Vielbauer, 1997; Baas, 2007, Montalvo&Kemp, 2008; Horbach et al., 2012). Er zijn echter nog weinig pogingen gedaan om de succesvolle marktintroductie van nieuwe milieutechnologieën te begrijpen vanuit de aanbodzijde. Dit alles ondanks het grote aantal incrementele milieu-innovaties door een groot aantal ondernemingen (Cleff & Rennings, 1999).

Dit onderzoek geeft inzicht in het proces van commercialisering van milieutechnologie in het MKB. Meer specifiek verschaft het onderzoek begrip van de sleutelfactoren en de mechanismen die het proces van commercialisering kenmerken. In dit proefschrift wordt de term ‘milieutechnologie’ gebruikt voor ‘end-of-pipe’ en milieuvriendelijke procestechnologieën die aangemerkt kunnen worden als incrementele milieu-innovaties.

Centraal in deze studie staat een theoretisch raamwerk voor het proces van nieuwe-productontwikkeling en de empirische onderbouwing daarvan. Om de karakteristieken van milieutechnologie te beschouwen zijn de determinanten van eco-innovatie in het raamwerk opgenomen. Er is een ‘convergent parallel mixed-method design’ toegepast (Creswell & Clark,

2011; Tashakkori & Teddlie, 1998). Dit onderzoeksdesign vergroot de geldigheid van de resultaten door tegelijkertijd statistisch-kwantitatief en kwalitatief onderzoek uit te voeren, en de resultaten daarvan te vergelijken en op hun verschillen te onderzoeken.

Het onderzoek leidde tot twaalf succesfactoren in het commercialiseren van milieutechnologie door bedrijven in het MKB, en het bleek mogelijk om een aanpak af te leiden voor het opschalen van milieutechnologie. De twaalf factoren omvatten vijf sleutelfactoren: ‘technologische superioriteit’, ‘technische betrouwbaarheid’, ‘markt onderzoeksvaardigheden’, ‘intensiteit van concurrentie’ en ‘marktpositionering’. Daarnaast zijn er zeven secundaire, onderliggende factoren: ‘technologische synergie’, ‘brede toepassing’, ‘technische ondersteuning’, ‘commitment en support van het management’, ‘partnerships met afnemers’, ‘milieuregelgeving’ en ‘ondersteuning door de overheid’. Op basis van deze bevindingen stelt de auteur een model voor van de commercialisering van milieutechnologieën. Dat model onderscheidt vier mechanismen, en de verbanden daartussen: technologie, markt, organisatie en milieu.

In de ontwikkeling van milieutechnologie dragen organisatie- en milieufactoren bij tot het verbeteren van de superioriteit en de betrouwbaarheid ervan. Organisatiefactoren zijn o.a. commitment en support van het management, markt onderzoeksvaardigheden en en technologische synergie. Hoogwaardige en betrouwbare milieutechnologie versterkt de factoren die een positief effect hebben op commercialisering – diversificatie van technologie, toepassing, technische ondersteuning, samenwerking met grote bedrijven en marktpositionering. De intensiteit van de concurrentie en milieuregelgeving in de doelmarkt kunnen an sich een positieve factor zijn. Dit model is een eerste poging om te begrijpen welke factoren bijdragen tot de commercialisering van milieutechnologie vanuit het standpunt van de aanbieder.

Deze studie draagt bij tot de literatuur en de praktijk. Ten eerste: het resultaat van deze studie voegt milieutechnologie toe als een specifiek deelgebied op het grotere gebied van onderzoek naar de commercialisering van technologie. Ten tweede: met de verworven inzichten in het proces van commercialisering van milieutechnologie levert deze studie een bijdrage aan de doelmatigheid van het overheidsbeleid ter bevordering van de commercialisering van milieutechnologie in het MKB.

Summary of Korean

환경 기술은 지속가능한 개발의 핵심 도구로써 전 세계적으로 관심도가 지속되고 있다. 독일의 Greentech(2018) 보고서에 따르면, 2016 년 기준으로 지속 가능한 물 관리, 폐기물 관리 및 재활용, 재료 효율성 등과 같은 주요 환경기술의 세계 시장 규모는 1 조 2,980 억 유로이며, 2025 년에는 2 조 2,590 억유로의 성장을 전망하고 있다. 한국은 환경기술 분야의 응용, 개발단계 R&D 프로그램의 예산을 매년 확대하고 있으며, 2018 년 환경부는 응용, 개발 단계의 R&D 프로그램에 1 억 1,200 만 유로를 지원했다. 일부 공개된 보고서에 따르면(ISTK, 2009; Jung et al., 2015), 환경기술 분야를 포함하여 한국의 정부지원 응용-R&D 사업의 사업화 성공률은(이 연구에서 사업화 성공은 시장 도입과 새로운 매출 창출로 정의된다) 미국, 영국 등과 같은 선진국에 비해서 낮은 수준으로 보인다. 한국에서 민간 부문의 기술 사업화를 촉진하려는 정부의 노력은 효율적인 예산 지출에 중점을 두고 있으며, 한국과 선진국 간의 기술 격차의 감소 등과 같은 기술 차원의 중요성이 주로 강조된다. 그러나 기술 사업화를 포함하는 포괄적인 신제품 개발 과정은 복잡하고 이해하기 어렵기 때문에 기술사업화 촉진 정책은 다양하고 도전적인 기업 활동에 대한 포괄적인 이해가 뒷받침되어야 한다(Datta et al., 2014).

지금까지 환경 혁신은 주로 수요 창출을 위한 혁신 확산의 관점에서 연구되었다(Coenen & Klein-Vielhauer, 1997; Baas, 2007, Montalvo & Kemp, 2008; Horbach et al., 2012). 점진적인 특성을 갖는 환경 기술은 이미 다수의 기업에서 발명하거나 적용하고 있음에도 불구하고(Cleff & Rennings, 1999), 기술공급자 측면에서 환경 기술의 사업화 성공을 포괄적으로 이해하려는 시도는 거의 없었다.

이 연구를 통해서 저자는 중소기업의 환경 기술 사업화 과정에 대한 통찰을 제공한다. 보다 구체적으로, 새로운 환경기술의 사업화 과정에 영향을 미치는 주요 요인과 메커니즘에(이 연구에서 메커니즘은 요인들의 상호 관계를 말한다.) 대한 포괄적인 이해를 제공한다. 이 논문에서 환경 기술은 점진적 혁신으로 분류될 수 있는 사후 처리 및 친환경 공정기술을 말한다. 이 연구의 이론적 근거는 신제품 개발 과정의

개념적 체계와 경험적 발견을 기초로 하였다. 환경 기술의 특성을 고려하기 위해 개념적 체계에는 환경 혁신의 확산 결정 요인이 추가되었다.

이 논문의 포괄적인 연구방법은 수렴적 병렬 설계(Creswell & Clark, 2011; Tashakkori & Teddlie, 1998)가 적용되었다. 수렴적 병렬 설계는(Creswell & Clark, 2011; Tashakkori & Teddlie, 1998) 통계적 정량적 연구와 정성적 연구를 동시에 수행하고 각 결과를 비교 및 대조하여 연구 결과의 타당성을 향상시킬 수 있다. 동시에 동일한 사례에 대해 진행된 정량적 및 정성적 연구는 성공 요인의 식별을 상호 보완하였으며, 정성적 연구는 성공 요인의 역학과 상관 관계에 대한 풍부한 이해를 제공하였다.

이 연구는 중소기업의 환경기술 사업화 과정에서 12 개의 성공 요인을 제시하고 요인 간의 메커니즘을 제시하였다. 12 개의 성공 요인은 다음과 같다: 5 개의 핵심 요인(technology superiority, technology reliability, market research skills, competitive intensity, competitive positioning), 7 개의 2 차, 기본 요인(technological synergy, broad application, downstream alliance partnership, good technical service, top management commitment and support, environmental regulatory, government support policy). 저자는 이 연구의 결과를 기초로 하여 환경기술 사업화에 대한 예비 모델을 제안하였다. 이 모델은 성공 요인들을 기술, 시장, 조직 및 환경의(시장 상황에 대한 정책 및 규제와 같은 사회적 환경을 의미한다.) 네 가지 클러스터로 분류하고 요인 간의 상호 관계를 보여준다. 이 모델에 따르면 조직 및 환경요인은(예, R&D 보조금 등과 같은 정부 지원 정책) 환경기술의 개발 과정에서 기술 우위(technology superiority)와 기술 신뢰성(technology reliability) 향상에 기여한다. 조직 요인에는 최고 경영진의 지원(top management commitment and support), 시장 조사 역량(market research skills), 기술적 시너지(technological synergy) 등이 포함된다. 환경기술의 기술 우위와 기술 신뢰성은 사업화 과정에서 적용 범위의 확장(broad application), 우수한 기술 서비스(good technical service), 대기업과의 하위흐름 협력(downstream alliance partnership), 경쟁 우위(competitive positioning) 등과 같은 사업화에 긍정적인 영향을 미치는 요인들을 지원한다. 목표 시장에서의 경쟁 강도(competitive intensity)와 환경 규제(environmental regulatory)는 그 자체로 기술 사업화에 긍정적인 요인이 될 수

있다. 이 모델은 기술 공급자의 측면에서 새로운 환경 기술의 사업화 성공에 어떤 요인이 어떻게 기여하는지를 포괄적으로 이해하기 위한 첫 번째 시도이다.

이 연구는 다음과 같은 정책적, 학문적 함의를 갖는다. 첫째, 이 연구의 결과는 기술 사업화에 관한 기존 연구 분야에 특정 하위분야로써 환경기술을 추가한다. 둘째, 이 연구는 정책 입안자와 정부지원 프로그램 관리자에게 환경기술 사업화 과정에 대한 통찰을 제공함으로써 정부의 중소기업 사업화 촉진 정책의 효율적인 운영에 기여할 수 있다.

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CHAPTER 1: Introduction

This study is about environmental technology and technological commercialization by technology suppliers. This study is designed to understand "why some companies succeed in commercialization and why others fail." This thesis, based on previous research on new product performance and technology commercialization, identifies factors that influence the commercialization of environmental technologies for SMEs. These factors include both internal (technology factors and organization factors) and external ones (market factors and environment factors) for a company. Furthermore, it provides an understanding of how identified factors affect the success and/or failure of environmental technologies commercialization. This thesis has the following implications for literature and practice: 1. This study adds environmental technology as a specific sub-field to existing research areas on technology commercialization (environmental technology covered in this thesis focus mainly on end-of-pipe technologies with incremental technological improvements). Furthermore, the author presents a comprehensive conceptual framework for commercialization of environmental technology. 2. This thesis provides stakeholders with insights into the commercialization of environmental technologies in SMEs.

The cases in this study are projects of SMEs that participate in South Korea's Environmental Technology Development Program. In Chapter 1, the author explains the problem consciousness from the social phenomena that motivated the development of this thesis and explains statements about theoretical problems, research questions, and research outlines (definitions, theoretical perspective, etc.).

1.1 Research background

The background of this thesis explains why environmental technologies and SMEs are important for sustainable development and economic development with evidence. In addition, it describes the government's efforts to support the development of environmental technologies for SMEs and explains the motivation behind developing this thesis, which is the starting point for the author's problem consciousness.

The contribution of SMEs to economic development and job creation is very high

(Newberry, 2006). According to the US Small Business Administration[3], there were 28.8 million small businesses in the US in 2013. Small businesses comprise 99.9% of all firms. Small businesses created 62% (8.3 million) of the net new private-sector jobs and account for 48.0% of private-sector employees. In the UK, 99.9% of the 5.2 million private sector businesses were SMEs in early 2014. SMEs account for 60% of private-sector employment and 47% of sales[4]. As of 2015, South Korea's SMEs accounted for 99.9% of all enterprises and 90.2% of private-sector employment. The proportion of sales was 53.9%.[5]

Entrepreneurship scholars emphasize that SMEs need an innovative edge to compete with large corporations (Schumpeter, 1982; Davidsson, 2004). In addition, scholars say that SMEs with features such as small size, simple organizational structure, and rapid decision-making are more likely to adapt to environmental changes and benefit from technology innovation than large organizations (Nooteboom, 1994; Vossen, 1998; Rosenbusch *et al.*, 2011). However, the process of commercializing technological innovations in which there is considerable uncertainty is a great challenge that can pose risks to SMEs that lack resources. According to Stevens and Burley (1997), in the pharmaceutical industry, one in 10,000 compounds succeeds as a new product and the time from discovery to market is >10 years, with a total cost of nearly $1 billion USD. Accordingly, developed countries[6] such as EU member states, the United States, and Japan operate government support policies (e.g. commercial R&D support, initial commercialization support, start-up support, and professional manpower support) to foster SMEs.

In South Korea, the budget for SME promotion programs was $14.8 billion USD in 2017, which accounts for 4.2% of the government's total spending budget[7]. Financial support accounted for 56.1% of the total. The budget for supporting the start-up and initial technology

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[3] http://www.sba.gov/advocacy

[4] Business population estimates for the UK and regions 2014, Department for business innovation & skills, 2014

[5] SME status indicators 2017, Korea Federation of SMEs, 2017

[6] The EU (27 countries) increased its R&D budget by 18.6% to €170 billion EUR in the next medium-term fiscal year (2014–2010). (EU 2011 Innovation union competitiveness report, 2011), The US Small Business Innovation Research Program runs a funding system for SME R&D and technology commercialization. (3.2% of the federal agency R&D budget by 2017) (Science and Technology Policy, 2011).

[7] Survey on the status of SME promotion in 2017, Small and Medium Business Administration, 2017

commercialization has also steadily increased. In 2015, the budget for SME R&D support accounted for 14.8% of the total budget for R&D support ($16.8 billion USD).[8]

In addition to sustainable development, interest in environmental technology is also expanding**.** According to a 2016 policy report published in Germany for sustainable development and the development of its environmental technology industry[9], the world market for major environmental technologies (e.g. sustainable water management, waste management and recycling, and material efficiency) was €1,298 billion EUR. It has been estimated to reach €2,259 billion EUR by 2025; the average annual growth rate is 7.03%. The global market size of major environmental technologies in 2025 was about 6.6 times that of South Korea's national GDP (€339.9 billion EUR in 2017). In South Korea, the market size for resource recycling management, water management, climate change response, and air-quality management technology were €4.8 billion EUR in 2015.[10] The value of technological innovation in the corporate environment is created by entering existing markets or creating new ones (Datta *et al.*, 2014). Thus, governments around the world are increasing their support for industrial R&D. In particular, the South Korean government's R&D budget was $17.1 billion USD in 2018, showing an increase of >60% over the last 10 years.[11] In 2018, the Ministry of Environment provided $129 million USD in R&D projects for the application and development phase. As of 2018, the Ministry of Environment operates 16 government-funded R&D programs.

Figure 1.1 shows the interest level for environmental technology over the last ten years using Google Trends. The highest search frequency is 100, which shows the relative interest for each year. The search category is business and industry. While interest in environmental technologies is slowly decreasing, the overall search frequency is consistently maintained at 50~80.

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[8] Analysis of the status and performance of SME R&D support, Korean Science and Technology Policy Institute, 2017

[9] Greentech made in Germany 2018, Federal Ministry for the environment, nature conservation, and nuclear safety, 2017

[10] Report on the environmental industry survey 2015, Ministry of Environment

[11] White paper of science and technology statistics, Ministry of Science and ICT, 2000

Figure 1.1

Search Trend of Environment Technology 2009-2018

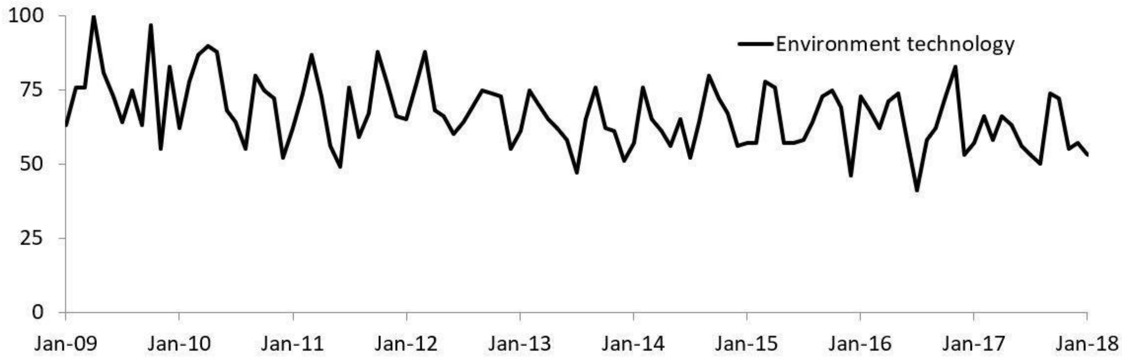
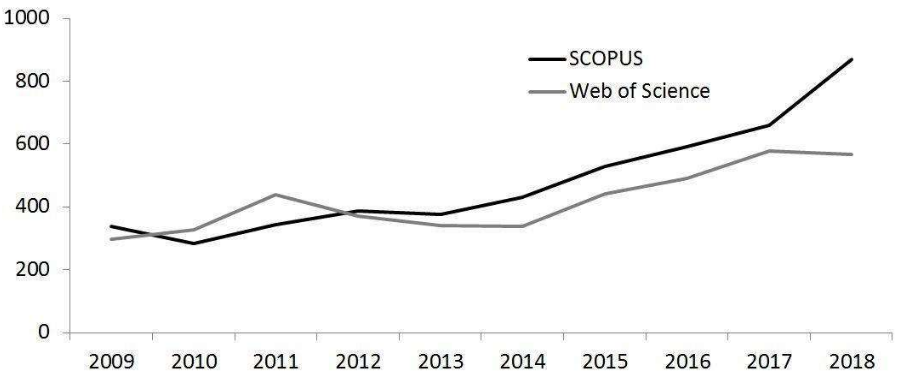


Figure 1.2 shows the number of articles related to environmental technology over the last 10 years; Web of Science and SCOPUS were used for this search.[12] On average, 450 articles are published each year, whereas the average for articles published over the last two years is 668; this number is increasing continuously.

Figure 1.2

Distribution of Publications Related to Environmental Technology 2009-2018



However, relatively few studies have focused on both environmental technology and SMEs (see Figure 1.3). In particular, among the 20 articles published in 2018, 10 articles are for research topics in business, management, and accounting and most of them focus on supply chain management and the acceptance of innovative technologies into SMEs.

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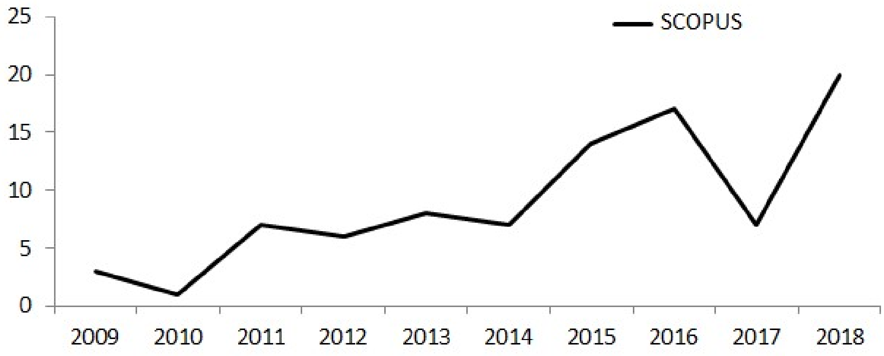
[12] Search criteria: keyword (environmental technology), document type (article), language (English), subject area (business [business economics], management and accounting, economics, econometrics and finance, social science, public administration).

Figure 1.3

Distribution of Publications Related to "Environmental Technology" and "SME" 2009-2018



The Environmental Technology Development Program provided as a target population of this thesis is a program to support R&D in the applied research stage of SMEs. At the applied research stage[13], the Environmental Technology Development Program accounts for >80% of the country's total R&D budget for the environmental sector. The Environmental Technology Development Program includes five sub-programs that support R&D at the applied research stage, and the support proportion of SMEs accounts for >90%.

The aims of these five programs are to promote the commercialization of environmental technologies, improve the eco-efficiency and competitiveness of the industrial sector, drive new growth engines for the environmental industry, and commercialize domestic advanced technologies. The main support areas are air-quality management, water management, soil/groundwater management, resource circulation management, and eco-friendly processes. Table 1.1 shows the project management process of the Environmental Technology Development Program. This process consists of planning, management, and evaluation. The Environmental Technology Development Program operates a technical committee, and proposals selected through the committee are selected by the expert group for the final project. After that, the operator selects the company to carry out the project through the announcement. The selection criteria include technology development goals and plans, commercialization plans, technology development, and commercialization capabilities. Subsequently, the projects

[13] According to Ryu and Choi (2015), government-funded R&D is divided into two types: basic research and applied research. Applied research includes research with practical and commercial characteristics and experimental development studies.

that have been judged to have succeeded in the development of technology in the mid-term and in their final evaluation are subjected to performance management for five years. Typically, the project lasts two to three years. The program is evaluated by the National Science and Technology Commission in the planning, implementation, and completion phases.

Table 1.1

Project Management Standard Process of Environmental Technology Development Program

Category	**Activities**	**Duration**
Project planning	- Project generation: Creation of project concepts and proposal preparation - Evaluation and selection of proposals	12 months
Project management	- Project selection: Determination of projects to support - Project monitoring: Communication of problems and results, assessment of substantive progress	24–36 months
Project evaluation	- Assessment of substantive and managerial accomplishments and deficiencies. - Fiscal auditing. - Performance management. - Collection of royalties from supported firms.	Five years

The direct outcomes of government-supported R&D programs targeting private companies are recognized as successful technology transfer and commercialization (Bozeman, 2000; Kimura, 2010). The South Korean government focused on implementing various national strategies under the "Technology Transfer Promotion Act" in 2000 to promote the successful commercialization of government-funded R&D projects. The government had promoted technology transfer activities between the public and private sectors in the industrial sector for ten years until 2006 and has created many venture capital funds; the government invested $9 billion USD in industry (Jung *et al.*, 2015). In addition, the government has continued efforts to improve the R&D investment efficiency and R&D project management efficiency. Despite these efforts, the success rate (it refers to market introduction and new sales generation) of the commercialization of government-funded R&D programs in South Korea's industrial sector during that period was <20%.[14] The success rate of commercialization in the

[14] Successful commercialization in R&D performance management is managed as the success of commercialization when sales are generated through technology transfer or commercialization.

Environmental Technology Development Program is also maintained at approximately 20%. When only targeting SMEs, the success rate of commercialization is even lower. A direct comparison cannot be made because the definition of success may be different, but according to some published reports (ISTK, 2009; Jung *et al.*, 2015), the success rate of commercialization in the United States and the United Kingdom is about 50% or more. These results reveal the limitations of the government's role in promoting technology commercialization.

In other words, public policymakers' efforts to focus on R&D spending only emphasized the importance of technology (e.g. the technological gap between Korea and developed countries). However, a comprehensive NPD process that includes technology commercialization, is one of the most complex and difficult to understand and involves various challenging corporate activities (Cooper, 1980; Datta *et al.*, 2014). Public policymakers and government-supported R&D program operators need policy planning and operations based on a comprehensive understanding of the factors and dynamics of technology commercialization success in terms of technology providers.

As mentioned above, economic, social, and academic interest in SMEs and environmental technologies is continually increasing. In particular, the importance of environmental technologies for sustainable development can be seen in the global market size. However, although the commercialization of innovative technologies has been a long-term research topic, there remains a lack of policy and academic studies that can provide insights into the commercializing environmental technologies. For example, some of the more recent energy innovation studies on the commercialization process (Rese et al., 2016; Shakeel et al., 2017) focused on some supply aspects of new products, and were limited to some factors such as government policy and collaboration. On the SMEs side, further studies on the success factors of environmental technology commercialization and their mechanisms are needed. In particular, it is important to provide policy makers of government policies targeting SMEs with a comprehensive understanding of the commercialization of environmental technology in SMEs.

1.2 Problem Statement

As mentioned in the previous section of this thesis, the activation of SMEs and environmental technologies is important in terms of economic and sustainable development, and their activation is a major policy issue. There is also increasing academic interest in environmental technologies from an economic perspective (see Figures 1.2 and 1.3). Despite the government's continuing efforts to expand the commercialization of government-supported development technologies, economic performance remains unsatisfactory (For example, the success rate of the commercialization of government-sponsored R&D programs in the industrial sector and applied research R&D programs in the environmental sector are 20%, which is very low compared to other developed countries). This shows the limitations of government policies to support technology transfer or commercialization. Recently, the government has been attempting policy research to understand the process of technology transfer and commercialization at both the industrial and firm level, but there is almost no environmental technology field. There is a need for a comprehensive study on the environmental technology commercialization of SMEs that can provide policymakers insights into the environmental technology commercialization from a technology supplier's perspective.

In previous studies (e.g. Coenen & Klein-Vielhauer, 1997; Baas, 2007, Montalvo & Kemp, 2008; Horbach *et al.*, 2012), eco-innovations (e.g. clean technology and energy innovation technology) have been studied in terms of the diffusion of innovations to create demand. In the field of energy innovation technology, some recent studies (e.g. Rese *et al.*, 2016; Shakeel et al., 2017) have attempted to understand the process of commercialization on the supplier side, but still focused on certain factors such as government support policies or collaboration. Incremental environmental innovations (e.g. end-of-pipe technologies and environmentally friendly processes) are already being developed or applied by most companies. According to Cleff and Rennings (1999), most innovative companies in the German industrial sector have long been involved in environmental innovation activities (For example, environmentally friendly product production, energy-saving, waste reduction, and reducing emissions). Some scholars argue that environmental innovation can also be motivated by general business goals such as profitability or product quality improvement (Beise & Rennings, 2005; Brécard *et al.*, 2009; Brouhle & Khanna, 2012; Medeiros *et al.*, 2014). In other words, environmental technologies require a comprehensive understanding of the commercialization of environmental technology from the perspectives of technology suppliers (the activities of companies that develop and commercialize technology) and diffusion theory.

Commercialization research from the technology supplier's perspective has mainly been studied in the field on new product performance and technology commercialization. Major scholars in the field on new product performance (e.g. Cooper, 1979; Cooper, 1980; Cooper and Kleinschmidt, 1987; 1996; Montoya-Weiss and Calantone, 1994) have tried to identify key factors that influence commercialization success[15]. Recent researches (Hora & Dutta, 2013; Malshe and Biemans, 2014; Shakeel *et al.*, 2017) has attempted to explain and predict phenomena related to the performance of new products in each industry (particularly in radical innovative products such as medical devices, renewable energy, ICT, and bio-tech), or verify various theories such as strategy, organizational theory, operational management, and economics theory through case studies. However, there have been few attempts to comprehensively understand the commercialization of environmental technology with incremental innovation characteristics. There is a need for academic research that can comprehensively understand environmental technology commercialization from the perspective of technology suppliers.

1.3 Research Questions

This study's purpose is to obtain academic and policy insights through understanding SMEs' commercialization of environmental technologies. Specifically, the author identifies significant factors that influence SMEs' commercialization of environmental technology and understands the mechanisms behind such factors. Furthermore, this study proposes a comprehensive framework for the successful commercialization of new environmental technologies

Meeting this general goal of this research will require answers to the following questions:

1. Which factors influence the commercialization of environmental technologies by SMEs?
2. How are the factors that influence the commercialization of environmental technologies by SMEs interrelated?

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[15] The definition of the success of new product development or technology commercialization is multidimensional and complex (Griffin & Page, 1993). However, according to recent research on technology commercialization, the success of commercialization can be summarized as “market introduction and new sales generation.”

1.4 Definitions

1.4.1 Environmental Technology

Beise and Rennings (2005) defined environmental innovation as new or modified processes, technologies, practices, systems and products to avoid or reduce environmental damage (Kemp & Arundel, 1998; Rennings, 2000; Rennings & Zwick, 2002). Skea (1995) categorized environmental technology as clean technologies, pollution control technologies, waste management, clean processes, recycling, and clean products. The term "environmental technology" is used synonymously with various terms such as green technology, clean technology, and sustainable technology. However, Gonzalez (2005) classified environmental technologies as Clean Technologies (CP) and End-of-Pipe (EOP) technologies in empirical studies on the adoption of clean technologies. According to Gonzalez (2005), pipe end technology refers to devices or facilities that are added to the end of production or treatment processes to convert primary emissions into manageable substances or to minimize environmental load on discharge. Clean technologies refer to changes in production processes that reduce the amount of waste and contaminants produced during either the production process or a product's entire lifecycle.[16] The South Korean Ministry of Environment defines environmental technologies as follows[17]: the terms "environmental technologies" means the technologies necessary for environmental conservation and control such as the prevention or reduction of environmental pollution or the restoration of polluted and damaged environments. The scope of the environmental technology considered in this thesis is included in the technology classified as environmental in South Korea's National Science and Technology Standard Classification System (see Table 1.2). South Korea's classification system reflects the OECD's recommendation system. The scope of environmental technologies considered in this study includes a wider range than the End-of-Pipe technologies defined by Gonzalez (2005)

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[16] The term "cleaner production" was developed by an expert working group in 1989 as advice for UNEP's "Industry and Environment Program" (Baas, 1990). This was defined as: "The conceptual and procedural approach to production that demands that all phases of the lifecycle of a product or of a process should be addressed with the objective of prevention or the minimization of short and long-term risks to humans and the environment."

[17] Development of and support for environmental technology act (2010).

and Kemp (1997). For example, "eco-friendly processes" and "eco-friendly materials, products" include some clean technologies.

Table 1.2

The Scope of Environmental Technology in this Study

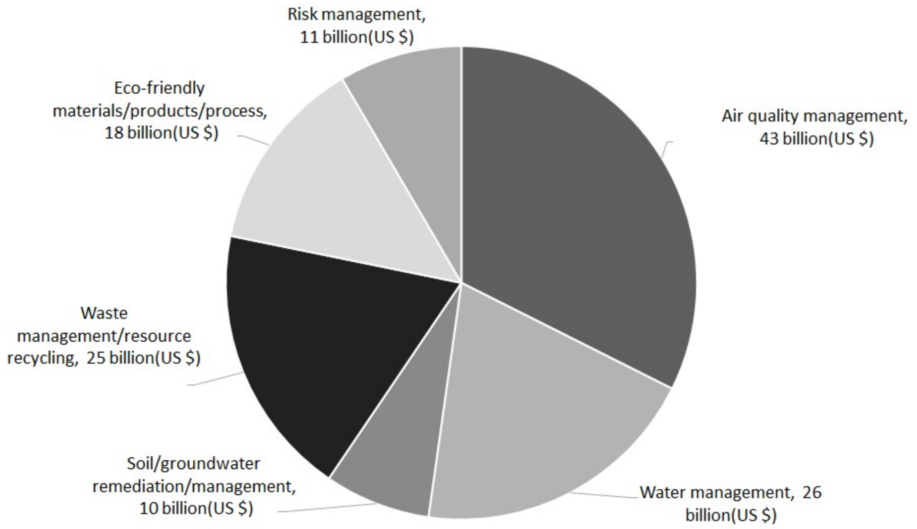
	Environmental Technology		Environmental Technology
1	Air-quality management	7	Environmental prediction/monitoring/evaluation
2	Water management	8	Eco-friendly materials/products
3	Soil/Groundwater remediation/management	9	Equipment/Facilities for environmental analysis and measurement
4	Ecology restoration/management	10	Eco-friendly processes
5	Noise/Vibration control and management	11	Risk assessment/management
6	Waste management/Resource recycling	12	Environmental health

Source: National science and technology standard classification system (National Science and Technology Council, 2012)

Figure 1.4 shows the market status of South Korea's major environmental sectors. The total revenue for the five major sectors was $133 billion USD. The following three sectors account for 71% of total sales: air-quality management, water management, and waste management and resource recycling.

Figure 1.4

The Market Status of Major Environmental Sectors in South Korea (2015)



Source: Report on the environmental industry survey 2015, Ministry of Environment

1.4.2 Technology Commercialization

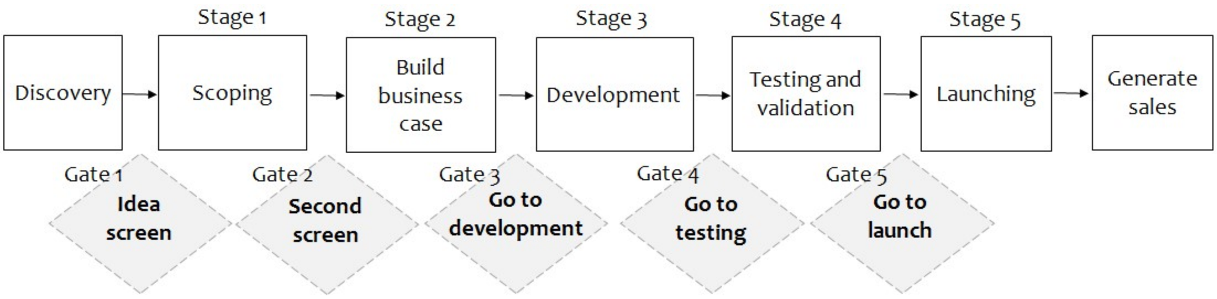
In this thesis, technical commercialization is defined using the broad concept proposed by Nevens (1990). The range of companies' technology commercialization activities follows the Stage-Gate process of Cooper (1986) (see Figure 1.5). In other words, in the context of SMEs' environmental technology, technology commercialization activities cover a range from idea development to market entry. The broad concept of technology commercialization means developing technologies through R&D planning and idea creation and applying them to new processes, new product development, and existing process and product improvements, creating a new lifecycle in the market (Nevens, 1990). According to Datta *et al.* (2014), in terms of innovation, some researchers have integrated commercialization activities into the definition of innovation (Burgelman *et al.*, 2008), while others have noted that the commercialization of innovation is an additional activity required to bring innovation into the market (Kelm *et al.*, 1995; Narayanan et al. 2000; Kwak, 2002; Andrew & Sirkin, 2003; Nambisan & Sawhney, 2007; Nerkar & Shane, 2007).

The scope of technology commercialization in this thesis is explained by the definition and scope of new product development proposed in the literature on new product performance. According to the literature, new product development is defined as "the activity of delivering perceptions of market opportunities (or ideas) to the market." Ulrich and Eppinger (2004: 2) defined new product development as a set of activities that begins with awareness of market opportunities and ends with production, sale, and delivery. In terms of management, Wheelwright and Clark (1992: Chapter 1) defined new product development as "Organization and Activity Management that can successfully bring products to market while reducing development time and costs."

Researchers have proposed a technology commercialization process model that helps make decisions that can improve the efficiency or effectiveness in technology innovation or new product development. In general, the technology commercialization process model is classified as either linear (Cooper, 1986; Rothwell & Zegveld, 1985; Andrew & Sirkin, 2007) or nonlinear (Jolly, 1997). Among previous studies, Cooper focused on the relationship between new product development success and process (Cooper, 1979; Cooper, 1980). This model consists of five gates and five stages from idea suggestion to market launch. In other words, this process model divides enterprises' technology commercialization activities into five stages at the project level and evaluates the project according to the decision criteria of five gateways assigned at each stage (see Figure 1.5). The decision criteria include factors that influence the success or failure of technology commercialization such as the characteristics of technology development, organization resources for project implementation, target market characteristics, and consumer needs.

Figure 1.5

Stage-Gate Model



- Gates 1 and 2: Review of the market orientation, market size and attractiveness, product merchandise, marketing capabilities of the company, consumer needs of the product, and the establishment of an intellectual property strategy
- Gates 3 and 4: Analysis of a company's financial capacity, review of development plan/preliminary driving/marketing plan, and project team composition
- Gate 5: Potential economic analysis, production planning, and market launching suitability review

Source: Cooper *et al.*, 2002

1.4.3 Technology Commercialization Success

In a very early new product performance study, Cooper (1979) pointed out that the definition of success in technology commercialization was inconsistent. The definition of success in technology commercialization could be applied differently depending on who was researching in which field. The measure of the success of technology commercialization is multidimensional and complex (Griffin & Page, 1993). Wang *et al.* (2003) defined the success of technology commercialization in terms of innovation diffusion based on surveys of experts or organizations involved in technology transfer or the commercialization of innovation. This literature argues that successful technology commercialization can be recognized as having been achieved by launching a new product and reaching the early majority group. The early majority refers to the fourth stage of diffusion in Rogers' (1994) five adopter categories. In a recent study, Dutta *et al.* (2014) categorized entrepreneurial activities related to the performance of innovation through extensive literature review studies. This literature defines a company's ability to commercialize technology as the ability to introduce innovation to the market and reach the mainstream market beyond its early adopters. The definition of success in technology commercialization can be summarized as cases in which technology development enters the market and sales are generated.

In this thesis, the successful commercialization of development technology is defined as the case where both non-financial (e.g. market launch of developed product, technology) and financial (e.g. new revenue by developed technology) performance are achieved from the perspective of technology suppliers.

1.5 Theoretical Perspective

This thesis seeks academic and practical recommendations through understanding the success of SMEs' commercialization of environmental technologies. More specifically, the author identifies factors that influence success in SMEs' commercialization of environmental technology and understands the mechanisms of factors.

This thesis has the following implications for literature and practice: 1. This study adds environmental technology as a specific sub-field to existing research areas on technology commercialization. Furthermore, the author proposes a comprehensive framework for the commercialization of environmental technologies. 2. This thesis provides stakeholders with insights into the commercialization of environmental technologies in SMEs.

A clear and comprehensive understanding of why some new products or technologies succeed while others fail has been an important research topic for many project managers and academic researchers. Commercialization research from the technology supplier's perspective has mainly been studied in the field on new product performance and technology commercialization. New product performance has been studied from various disciplines in different areas. Studies on new product performance include strategy planning, management, marketing, economics, and other multidisciplinary domains. As such, new product performance should be described in a comprehensive framework of strategy, organizational theory, operational management, and economics theory. Recent studies on new product performance have been based on various theories for explaining and predicting phenomena related to each field. There is no theory for a comprehensive understanding of new product performance and technology commercialization. Loch and Kavadias (2008: Chapter 1) said that there probably is no "new product development theory" in the integrated theory study on new product development. Loch and Kavadias (2008) attempted to understand new product development research as an "operations management" framework in terms of processes (a repeated series of tasks from opportunity to market). Examples include the Deshmukh and Chikte (1980) process model based on operational management theory, the Brown and Eisenhardt (1995) framework that highlights organizational (top management and project leader) success factors, and the Krishnan and Ulrich (2001) classification. Each of these new product development process-level frameworks highlights specific theories and phenomena within new product development but does not aim at a comprehensive perspective. Based on previous literatures on new product performance and technology commercialization (Cooper, 1979; Cooper, 1980; Cooper & Kleinschmidt, 1987; 1996; Montoya-Weiss & Calantone, 1994; Henard & Szymanski, 2001; Henard & Szymanski, 2001), this thesis attempts to understand the success factors behind the commercialization of environmental technologies by classifying them as technology, organization, market, and environment factors.

In conclusion, the theoretical basis of this thesis is the empirical evidence and new product development process framework of previous literature on new product performance and technology commercialization. Research on the diffusion of eco-innovations such as Green *et al.* (1994), Kemp (1997), and Rennings (2000) (particularly the determinants for innovation diffusion), was the basis for understanding the environmental factors (i.g. government support policy and environmental regulation) in commercialization of environmental technologies.

1.6 The Significance of this Study

Many of the policymakers involved in government-funded R&D and early commercialization support policy wonder why some projects succeed while others fail. The main stakeholders of this study are public policymakers. This thesis provides stakeholders with insights into the commercialization of environmental technologies in SMEs. In particular, policymakers can identify improvements in the implementation and management of government-supported commercial R&D projects in terms of new product performance.

In terms of research methodology, this thesis produces valuable results because it is a mixed method study. The limitations of statistical-quantitative research in this area have been raised continuously in the literature[18] (e.g. Montaya-Weiss & Clatone, 1994; Balachandra & Friar, 1997; Ernst, 2002; Henard & Szymanski, 2001; Kirchberger & Pohl, 2016). Recently, studies in this field (e.g. Morgan *et al.*, 2015; Lin *et al.*, 2015; Eling *et al.*, 2013; Rese *et al.*, 2016; Jo & Park, 2017) have focused on supplementing strict statistical methods such as the application of structural equations. This thesis both validates and complements the results of the two studies through a convergent parallel mixed-method design that simultaneously conducts quantitative and qualitative research in one study. The results of this study provide more understanding than previous statistical-deductive studies on new product performance and technology commercialization.

This thesis consists of seven chapters.

Chapter 2 gives the results of literature review. It touches upon the proposed success factors and dynamics in previous researches on new product performance and technology commercialization.

Chapter 3 describes the research design and explains the comprehensive methodology of this thesis. Specifically, it presents the validity of the research methodology, the convergent parallel method design (including its advantages), and the overall visual model of this thesis.

Chapter 4 conducts quantitative research based on the conceptual framework for technology commercialization proposed in Chapter 2. It provides significant success factors for SMEs' commercialization of environmental technologies. The statistical analysis method uses binary logistic regression.

Chapter 5 conducts qualitative research. In the qualitative research, the collected qualitative data is analyzed through the constant comparative method (Maykut & Morehouse, 1994) based on a grounded theory approach (Strauss & Corbin, 1990). It provides an in-depth understanding of what key factors, mechanisms and dynamics influence the success of SMEs in commercializing environmental technologies.

Chapter 6 merges and interprets the quantitative and qualitative findings of this thesis. Convergent parallel design, which is a comprehensive research method in this thesis, uses the term “merging” as defined in Creswell and Clark (2011) and Tashakkori and Teddlie (1998).

[18] For example, limited experience by a respondent, sample size, lack of statistical validity and reliability of verification results, difficulty in comparisons between studies using aggregate variables, and limitations in the interpretation of results.

“Merge” in this study means “comparison and contrast” analysis. Quantitative and qualitative findings are mutually verified and complemented by merging. Finally, it provides academic and policy insights into the success or failure of SMEs’ commercialization of environmental technologies.

Chapter 7 presents the conclusions of this study and suggestions for future research. Research questions are reviewed in terms of the findings presented in the previous chapter and summarizes the comprehensive contribution of knowledge.

CHAPTER 2: Literature Review

This thesis seeks academic and policy insights through understanding SMEs' commercialization of environmental technologies. Specifically, the author identifies significant factors that influence SMEs' commercialization of environmental technology, and tries to understand the factors' mechanisms (in this thesis, "mechanism" refers to the interrelationship between factors). Furthermore, this study aims to understand the dynamics of the success of SMEs' commercialization of environmental technologies. Therefore, a literature review was conducted to collect and analyze all relevant literature in the field through the systematic retrieval of literature on new product performance and technology commercialization. The literature review of this thesis attempts to provide a broader understanding.

First, this thesis reviews the theory related to research on new product performance and technology commercialization, which is the theoretical basis of this thesis. More specifically, to obtain an in-depth understanding of the research questions in this thesis, previous literature on new product performance are identified and their mechanisms are reviewed. In addition, the dynamics of technology commercialization project success are understood. The results of the literature review provide a basis for the quantitative (Chapter 4) and qualitative studies (Chapter 5) of this thesis.
Second, the recent methodological characteristics of research on new product performance and technology commercialization are reviewed and the methodological implications are drawn.

2.1 Literature Review Strategy

The literature review in this thesis consists of two folders. First, theories related to NPD research are explored. Second, the methodological implications related to NPD research are derived.

1. Material collection: The material to be collected is defined. The unit of analysis (i.e. single articles) is filtered
2. Theoretical framework review: Considering the purpose of this study, theories related to new product performance and technology commercialization are reviewed. The literature review of this thesis identifies the factors related to success and/or failure of technology

commercialization found in previous studies, and focuses on understanding the mechanisms and success dynamics among the factors. In the literature review process, the classification of innovation (gradual innovation, radical innovation) and the classification of technology providers (large enterprises, SMEs) are not considered.

3. Methodological characteristics review: Methodological features are reviewed based on recent literature on new product performance and technology commercialization.

2.1.1 Delimitations

To clearly define the scope of the literature review, the following exclusion criteria were established (Seuring & Muller, 2008):

1. This analysis is solely aimed at articles in peer-reviewed scientific journals written in English.
2. Time range: Includes all articles. However, a review of the methodological features of recent studies on new product performance and technology commercialization has covered the literature over the last five years. A review of the methodological features of recent literature to identify the developmental stage of the theory does not require a long time period.
3. Scope of the technology commercialization process: The scope of the review for providing a conceptual framework for the factors influencing technology commercialization is based on the scope of the enterprise decision criteria proposed in the process model of Cooper (1986). Therefore, it excludes studies that focus on technical performance (e.g. technical performance, performance to spec, and met quality guidelines). It excludes empirical studies that analyze nonprofit organizations (e.g. public institutions and universities) that do not directly undertake technology commercialization processes (this refers to the launch and generation sales stage of the process model of Cooper (1986)) in terms of technology supply.

2.1.2 The Search for Literature

The keywords selected for the literature review were “new product development,” “R&D project,” “technology innovation,” “technology,” and “environmental technology.” These keywords were used in the literature search in combination with “commercial or commercialization,” “success or failure factor,” “barrier,” “SME,” “diffusion,” and “literature review.”

The databases used to search for related articles were “Web of Science,” “SCOPUS,” and “Google Scholar.”

2.2 Results of the Literature Review

Six hundred and three works were selected initially through duplicate review and title review. The selected works were reviewed according to delimitation criteria and 132 were selected after the abstract screening stage. After full-text reviews, 119 works were finally selected.

2.2.1 Theories Related to Research on New Product Performance and Technology Commercialization

Many innovation commercialization empirical studies focusing on the innovation process in the 1970s have attempted to determine "factors associated with the success or failure of innovation" (Rothwell, 1992). Cooper (1980) added factors such as the nature of the product (uniqueness, superiority and economic benefit) and the nature of the market (intensity of market need, market growth rate, and market size) in addition to the success type of innovation project implementation in new product performance research. Since then, innovation commercialization has attempted to derive significant factors through researches on new product performance and technology commercialization; many review articles and meta-analyses have been conducted on factors influencing based on these empirical studies (Lilien and Yoon, 1989; Montoya-Weiss and Calantone, 1994; Brown and Eisenhardt, 1995; Balachandra and Friar, 1997; Henard and Szymanski, Ernst, 2002; Datta *et al.*, 2014; Kirchberger and Pohl, 2016). These studies have collected and reviewed the factors from empirical research on the commercialization of innovation, new product performance, and R&D project performance to suggest key factors. The author reviews the theoretical framework of research on technology commercialization, which is the theoretical basis of this thesis, and proposes a conceptual framework related to technology commercialization.

2.2.1.1 Theoretical Framework for Technology Commercialization

Since the 1990s, research has been carried out by many researchers (e.g. Brown & Eisenhardt, 1995; Balachandra & Friar, 1997; Krishnan & Ulrich, 2001; Loch & Kavadias, 2008; Datta *et al.*, 2014) to understand for new product performance and new product development process. However, the author did not find any study that clearly suggested a theoretical framework for a comprehensive understanding of new product performance or technology commercialization. Datta *et al.* (2014) gives two reasons why innovation commercialization is not clearly understood (Datta *et al.* (2014) integrated new product performance and new product development processes into the commercialization of innovation). First, the commercialization of innovation is dealt with in many areas, including economics, management, marketing, entrepreneurship, and strategy; each field has its own research agenda and unique variables, making it difficult to see comprehensive views. Second, most prior work has focused on specific areas such as sources of innovation or protection of intellectual property rights. Loch and Kavadias (2008: Chapter 1) pointed out in the integrated theory study on new product development that "new product development theory" does not exist and there is no consensus regarding whether it exists. However, there have been attempts to develop factor models that influence the success of technology commercialization focused on the new product development process. The influential framework of new product development research presented by Loch and Kavadias (2008: Chapter 1) includes: Deshmukh and Chikte (1980), Brown and Eisenhardt (1995), and Krishnan and Ulrich (2001). Deshmukh and Chikte (1980) developed a new product development process framework focused on resource allocation in R&D and commercialization activities from a decision theory-based perspective. Deshmukh and Chikte (1980)'s process model contributes to improving the essential functions and resource efficiency for a company's new product development project. Brown and Eisenhardt (1995) proposed a communication web model that emphasizes the importance of a company's top management and the ability to communicate based on empirical research on new product development factors. The framework demonstrates that project leader- and senior management-based management systems can strongly impact new product development project success by effectively communicating decisions, information, and support within an organization. Krishnan and Ulrich (2001)'s framework includes three fundamental elements in new product development decision-making: product performance (market, design), supply chain (including organization issues), and portfolio selection. Each of these new product development process-level frameworks emphasize specific theories and phenomena within new product development but do not aim at a comprehensive perspective (Loch and Kavadias, 2008).

This thesis seeks academic and practical recommendation through understanding of SMEs' commercialization of environmental technologies. To answer the research questions in this thesis, the author needs a framework that covers both the new product development process level and product, organization, market, and environment characteristics (in particular, public sector policy, regulation, public R&D subsidy, etc.). This thesis proposes a conceptual framework based on the empirical evidence or framework from previous research that describes the factors and success dynamics in the new product development process. This conceptual framework and the dynamics of the process are a theoretical basis for the quantitative (Chapter 4) and qualitative studies (Chapter 5) in this thesis.

2.2.1.2 Toward a Conceptual Framework

The commercialization of innovation in terms of technology providers has been extensively studied for more than 40 years since pioneering research by Cooper (1979) and Maidique and Zirger (1985). Early on, Cooper and Kleinschmidt (1987) and Maidique and Zirger (1985) studied the commercialization of a product or technology from a technology developer perspective (more specifically, the aspect of a company that develops technology or products and promotes commercialization activities), based on new product performance and product innovation. Environmental technology has been studied in terms of the diffusion of eco-innovation. Green *et al.* (1994), Porter and van der Linde (1995a,b), Kemp (1997), and Rennings (2000) studied the determinants of the diffusion of environmental innovation based on the theory of innovation diffusion. This section collects and reviews the factors from previous literature and understands the mechanisms between these factors. The determinants and dynamics of diffusion (e.g. regulatory push, Policy pull) are understood from the literature on environmental innovation diffusion. Furthermore, success dynamics are understood. The author proposes a conceptual framework for technology commercialization based on an understanding of factors.

2.2.1.2.1 Classification of Factors Influencing Related to Technology Commercialization

Cooper sought to understand the following factors in new product development studies: new product development process (e.g. stage-gate process), technology characteristics, and organization characteristics (Cooper, 1979; Cooper, 1980; Cooper and Kleinschmidt, 1987; 1996). Montoya-Weiss and Calantone (1994) defined and categorized variables through a comprehensive review of new product performance in a meta-analysis study. Montoya-Weiss and Calantone (1994) classified the predictors of innovation success into strategic factors (e.g.

product advantage, technological synergy, company resources, strategy, and marketing synergy), development process factors (e.g. technical activities, marketing activities, protocol, top management support, pre-develop. act., speed to market, financial, business analysis, and costs), market environment factors (e.g. market potential, market competitiveness, and environment), and organizational factors (e.g. internal/external relations and organizational factors).

Henard and Szymanski (2001) classified predictors as product characteristics, firm strategy characteristics (technological synergy, dedicated human resources, and dedicated R&D resources), firm process characteristics (marketing proficiency, market orientation, customer input, and senior management support), and marketplace characteristics (competitive response intensity and market potential) in a broad meta-analytical study of the literature on new product performance.

According to previous literature on new product performance and technology commercialization, the factors influencing commercialization can be classified as technology, organization, and market characteristics. The author added environment characteristics to take into account the environmental technology feature. Environment factors include policy pull and regulation push, which are suggested as key determinants in environmental innovation diffusion research (e.g. Green *et al.*, 1994; Kemp, 1997; Rennings, 2000). Based on the existing literature on new product performance and technology commercialization, the author comes to understand the factors of commercialization in the technology commercialization process by classifying them as technology characteristics, organization characteristics, market characteristics, and environment characteristics.

2.2.1.2.2 Factors and Mechanism

Based on the previous literature, the author presents the factors that affect new product performance categorized by technology, organization, market, and environment characteristics. This section identifies factors according to each classification and understands the mechanism. The understanding of technology commercialization factors in this thesis is the foundation of the conceptual framework.

- **Technology Characteristics**

Product Superiority

According to Cooper (1979; 1980) and Cooper and Kleinschmidt (1987), product superiority integrates unique features for customers and has higher quality than competitive products (e.g. tighter specifications, stronger, longer-lasting, and more reliable), and helps meet higher customer needs. Product superiority is referred to as the product differential advantage and includes the following factors: a high performance-to-cost ratio and economic advantages (cost–benefit) to customers. Product superiority can include the ease of implementation for a developed product. According to Ettlie (1982), a product's ease of implementation can be further driven by factors such as the presence of prototypes, offsetting predicted production problems, ease of communication of advantages and benefits, and enabling previously impossible things. According to Balachandra and Friar (1997), product superiority is also expressed as a perceived value and has been recognized as a key success factor in new product development and R&D project performance research (Maidique & Zirger, 1984). In summary, "product superiority" includes high quality, meeting customer needs, technology completeness, and ease of technology implementation, which can serve as a catalyst for technology commercialization success in a competitive marketplace. Product superiority can work as a prerequisite for product reliability, top management commitment and support, and strategic partnerships.

Technological (or Production) Synergy (or Proficiency)

According to Cooper (1979), Cooper and Kleinschmidt (1987), and Montoya-Weiss and Calantone (1994), technological synergy is defined as "a good fit between a product's technology and a firm's technological resources and skills." According to their empirical studies, companies with a foundation in technical engineering, production, and resources are typically proficient in technical and production activities (e.g. preliminary technical assessment, product development, pilot (or prototype) testing, pilot production, and production start-up). Technological synergy helps to better understand products, design skills, and production processes. Henard and Szymanski (2001) defined technological synergy as "congruence between the existing technological skills of the firm and the technological skills needed for a new product initiative successfully." In summary, "technological synergy" supports technology development and production activities (particularly new product design, technology development, and production processes) to help improve product superiority and technology competitiveness. Technological synergies give companies competitive technological advantages early in the new product development project, thus increasing the likelihood of technology commercialization success.

First to Market (Early to Market, New, and Unique)[19]

According to Cooper (1979; 1980), which is an early work in this field, the “first to market” factor (e.g. new, unique, or different) that can be expressed as product uniqueness is not the single factor that determines success. He said that the “first-introduced” advantages are nearly equally balanced by many pitfalls and shortcomings. Product uniqueness and innovations as factors related to “first to market” must be accompanied by product superiority. In addition, it must be somehow related to market complexity factors such as customer needs, preferences, and usage patterns. According to Balachandra and Friar (1997), the importance of the “first to market” factor depends on whether a developed product is high- or low-tech. For example, in an empirical study of high-tech electronics products in the United States, Maidique and Zirger (1985) suggested “faster market entry” as a key factor for new product success. In conclusion, the “first to market” factor may vary in importance depending on the researcher or context (e.g. industry or innovation characteristics). In summary, “first to market” can be understood as an advantage of market preoccupation based on product uniqueness and “early market entrants” may be a positive factor for new product success in a competitive environment market (this does not mean a strong competitive market presence).

▪ **Organization Characteristics**

Top Management Commitment to and Visible Support for Innovation

Rothwell (1992) asserted the absolute importance of top management commitment and visible support to overcome barriers and resistance to innovation that is common among businesses. Ernst (2002) noted that senior management's perception of the value of a new product positively impacts on new product success. Firms need huge expenditures for market research and entry into new products (Ernst, 2002) In other words, the top management’s commitment and support is positively related to sufficient physical support for market-oriented activities (Cooper, 1979; 1980) that have been recognized as success factors for new product

[19] “First to market” should be distinguished from the “market existence” factor (Balachandra and Friar, 1997). “Market existence” can be measured as innovation in an existing market or innovations that require the creation of a completely new market.

development projects. In addition, because innovation is an inherently high-risk business, the top management's acceptance of risk can also play an important role in the commercialization success of innovations (Rothwell, 1992). According to the new product development framework of Brown and Eisenhardt (1995), support and control of senior management positively impacts new product performance by contributing to improved efficiency, including product concept effectiveness and process performance. In summary, the top management's positive perception of new product development projects on the SMEs side significantly impacts decision-making regarding resource inputs in technology development and marketing processes, project persistence, and risk acceptance. In turn, this can act as a key factor in the successful commercialization of technology.

People and Financial Resources

In an empirical study of 161 companies, Cooper and Kleinschmidt (1996) found key drivers/barriers to new product performance. This literature argues that resource shortages (in particular, human and money resources) are a barrier to new product performance as they affect the sustainability of new product projects. Lack of resources often works as a cause of poor-quality products and poorly executed projects (Cooper and Kleinschmidt, 1996). As a result, poor resource support in the early stages of the new product development project results in low technology completeness and marketing failures in subsequent new product development processes. Montoya-Weiss and Calantone (1994) described this as "company resources." The literature defined company resources as "the compatibility of the resource base of the firm with the requirements of the project." Henard and Szymanski (2001), through a meta-analysis of new product performance literature, suggested that dedicated resources is one of the most influential factors for new product performance. "Dedicated resources" are classified as human resources and R&D resources. This literature defines "dedicated resources" as "focused commitment of personnel resources to a new product" and "commitment of R&D resources to a new product initiative." Ernst (2002) emphasized the importance of market orientation. Strong market orientation for new product development projects can only be achieved if sufficient resources are available to support market research and the market entry of new products (Ernst, 2002). For companies implementing new product development projects, the use of sufficient resources to strengthen market orientation should essentially reflect the senior management's perception of new product development projects.

Market Knowledge and Marketing Proficiency (Market Research Skills, Market Proficiency)

According to Cooper (1979; 1980), successful companies are proficient in market-oriented activities; these include market assessment, market research, test markets, and market launches. In other words, a successful new product development requires an understanding of important aspects of the market such as customer needs, price sensitivity, market potential, and the competitive environment. Successful new product development projects should integrate technical research with market research (Cooper, 1980). Ernst (2002) emphasized continuous information updates through market research throughout the new product development process. Information gained through market research includes an understanding of customer needs (Parry & Song, 1994), research on market potential (Maidique and Zirger, 1984), and research on market competition (Mishra *et al.*, 1996) (Ernst, 2002). A company's strong market understanding can have positive impacts throughout the new product development process, including idea generation, development technology selection, customer needs identification, and sales.

Strategic Alliance Partnership

Previous empirical research (Hagedoorn & Schakenraad, 1994; Park *et al.*, 2004, Fabrizio, 2009) suggested that if a technology alliance partnership is formed in the early stages of NPD (e.g. venture establishment or R&D stage), companies can have a significant positive impact on new product performance. Fabrizio (2009) examined the relationship between a firm's absorptive capacity-building activities (e.g. collaboration with research universities, R&D expenditures, and research staff supplementation) and the performance of new inventions through quantitative and statistical studies. He proposed cooperation with research universities at the technological development stage to improve the performance of new inventions. According to a case study by Aarikka-Stenroos and Sandberg (2012), innovative companies need relational resources when moving from R&D tasks to commercialization tasks. This literature has confirmed that relational resources (e.g. commercialization capabilities based on networks such as distribution, marketing communications, and relationship mediation) facilitated the commercialization success of innovation companies.

Some researchers (e.g. Rosenbusch *et al.*, 2011) argued against previous studies in this field. Rosenbusch argued that innovation projects focused on external cooperation at the technology development stage do not help SMEs improve their performance. In his meta-analysis, he argued that working with external partners in the R&D phase could extend the duration of innovation projects and incur large transaction costs in the form of closer coordination, oversight, or intellectual property protection efforts.

Dutta and Hora (2017) examined the impact of strategic alliance partnerships (e.g. upstream alliance partnership or downstream alliance partnership) on commercialization through a quantitative empirical study of entrepreneurship ventures. According to their findings, entrepreneurship venture companies benefit from newly developed products through upstream alliances. Upstream alliances include the advanced knowledge of scientists at research universities, the use of state-of-the-art laboratory equipment, and postgraduate workforce support. Venture firms were provided with complementary resources such as market and customer knowledge, production asset bases, distribution channels, and marketing capabilities through downstream alliance partnerships. One interesting aspect of Dutta and Hora (2017) is that the technological partnerships in the technology development process they describe as "upstream partnerships" positively influenced the success of inventions but not the success of commercialization. However, Walsh *et al.* (2016) demonstrated that vertical collaborations have a significant positive effect on commercial success through statistical studies using the US patent information database. For example, cooperation with customers in the technology development stage. Through vertical cooperation, firms can fully reflect the requirements of the target market at the research and development stage, which can be a catalyst for successful commercialization.

Customer Linkage (Customer Input)

Users play an important role in the process of invention and early innovation (Rothwell, 1992). The ability to design flexible products with respect to user adaptation allows customers to contribute significantly to product improvement (Rothwell, 1992). Datta *et al.* (2014) proposed "maximize the fit with customer requirements" as a condition for successful product development in the innovation development process. Involving customers can match their needs to development projects (Cristiano *et al.*, 2001; Lilien *et al.*, 2002). Ernst (2002) expressed "customer linkage" as "customer integration" in a study on the success of new product development. According to him, the benefits of customer integration can increase in the early or late stages of the new product development process. In particular, integrating customer specifications into new product initiatives can improve new product performance (Henard & Szymanski, 2001).

▪ **Market Characteristics**

Target Market Size (Market Potential)

Interestingly, market potential did not predict the potential for commercialization according to Ettlie's (1982) study of 40 federally sponsored innovation projects. Ettlie suggested that the favorable price competitiveness of products rather than market potential was a major predictor of the commercialization success of innovation projects. Price competitiveness is a concept that can be included in the technical superiority proposed by Cooper (1979; 1980) and Cooper and Kleinschmidt (1987). However, the major new product development process researchers Cooper (1981), Merrifield (1981), and Balachandra (1989) cited the expected growth rate of the product market as one business aspect of new product decisions. In addition, they argued that new products introduced into a growing market could have greater potential for success. In previous studies, market potential was reported as either an important factor or an insignificant factor (Montoya-Weiss & Calantone, 2994). However, it is clear that a strong market already existing rather than just a potential market presents a good opportunity for new product success (Islei *et al.*, 1991). In particular, existing markets can reduce the difficulty of customer research and forecasting (Balachandra & Friar, 1997).

Uncertainty

Ragatz *et al.* (2002) demonstrated empirically that the presence of high uncertainty can reduce project performance due to complexity. In particular, unexpected complexity affects the deterioration of product quality, and increases both development time and development costs (Ragatz *et al.*, 2002). In the case of gradual innovation, uncertainty can be overcome by very thorough market analysis. However, in the case of radical innovation, since there may be no current market, market uncertainty can greatly influence the success of technology commercialization (Leonard-Barton & Wilson, 1994; Balachandra & Friar, 1997).

Competitive Positioning

Hooley *et al.* (2001) proposed a theoretical model of the relationship between corporate competitive positioning and corporate performance based on the theory of the "resource-based view of the firm”. According to Hooley *et al.* (2001), companies can improve their performance (mainly economic performance) based on their competitive positioning, which is created based on marketing assets and marketing capabilities. Specifically, the company’s reputation, branding, customer relationships, price, quality, service, and degree of customization offered to its customers can help it gain a competitive advantage in market offerings.

Competitive Intensity

Balachandra and Friar (1997) conducted extensive literature reviews on the performance of new product development and R&D projects. The study found that a competitive environment in the market could affect the success or failure of new product development projects. The details are as follows. A high percentage of new product introductions in the market indicates that a product is in the growth stage. This creates good opportunities for a new product (Balachandra, 1989; Islei *et al.*, 1991). Higher product introduction rates mean greater competition, which is a strong negative factor for the success of new products (Cooper, 1979; 1980; Yoon & Lilien, 1989; Maidique and Zirger, 1985). However, the presence of simple competitors in a market does not affect new product performance and the intensity of competition, such as strong competition can be an obstacle to commercial success (Cooper, 1980).

▪ **Environmental Characteristics**

Government Support Policies, Environmental Regulation

Understanding the relationship between environmental innovation (eco-innovation) and government support policies and regulations first requires an understanding of the characteristics of environmental technology.

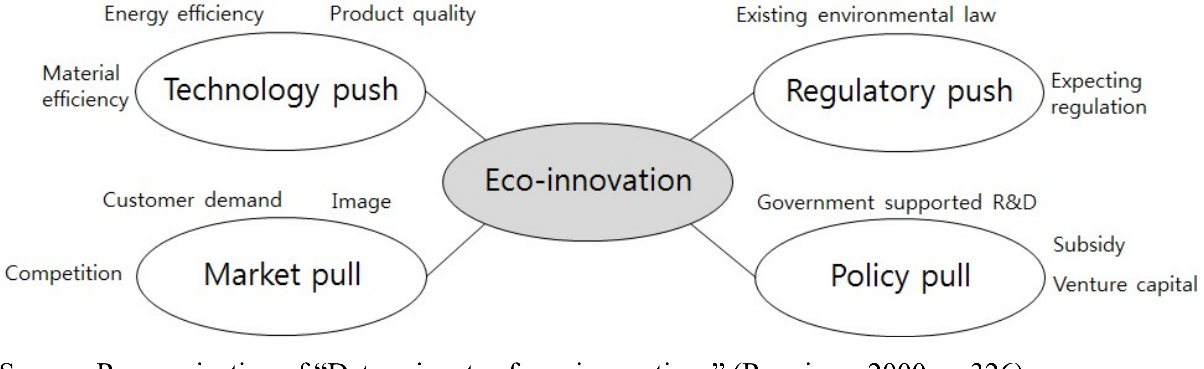
Eco-innovation produces positive spillover (Rennings, 2000). The positive spillovers of eco-innovation are due to their low external costs compared to the products or technologies that are competing in the market. These positive spillovers reduce the incentives for companies to invest in eco-innovation (Rennings, 2000). Accordingly, many scholars (Green *et al.*, 1994; Porter & van der Linde, 1995a,b; Kemp, 1997; Faucheux & Nicolai, 1998, Rennings, 2000, Horbach, 2008; Horbach *et al.*, 2012) have studied eco-innovation based on innovation diffusion theory. Through empirical research, they proposed innovation support policies (e.g. government support R&D, venture capital, and subsidy) and environmental regulations as key determinants for the diffusion of eco-innovation.

Empirical evidence from Pavitt (1984) suggests that the main debate in the study of the diffusion of eco-innovation is related to both technology push and market pull. Rennings (2000) proposed the determinants of eco-innovation from the perspective of the innovation process through literature review studies. He proposed three factors as determinants: technology push (e.g. material efficiency, product quality, energy efficiency), regulatory push (e.g. existing environmental law, expected regulation), and market pull (e.g. customer demand, image, competition). Technology push includes technical incentives such as saving energy and reducing production costs in the production of consumers' products. The market pull includes consumer preferences for images of green products or technologies.

Finally, regulatory push includes existing environmental regulations and expecting environmental regulations. Figure 2.1 shows the determinants of the development and diffusion of eco-innovation. The author adds a policy pull (e.g. government subsidies for the adoption of eco-innovation and innovation support programs) factor in the diffusion stage proposed by Kemp (1997). Kemp (1997) proposed new technology opportunities and the need for institutional support for clean technology in the determinants of technological change. New technology opportunities represent incremental improvements in end-of-pipe technologies that stem from new environmental protection policies (this may include greenhouse gas reduction policies and PM (particulate matter) reduction policy) and strict environmental regulations. Institutional support for clean technology includes economic incentive policies (subsidy) for technology adoption, technical support (public R&D subsidies), and other regulatory measures (energy tax and the mandatory use or production of clean technology).

Figure 2.1

Determinants of Eco-innovations



Source: Reorganization of "Determinants of eco-innovations" (Rennings, 2000, p. 326)

Companies can carry out government-sponsored R&D projects to maintain a competitive advantage in the market internally and to have internal resources directly related to performance (Watjatrakul, 2005).

▪ **Dissemination of Large-scale Environmental Technology Systems**

Kanda *et al.* (2016) proposed components that should be included in the business model for the dissemination of large-scale environmental technology systems through qualitative research, targeting five environmental technology system companies. These proposed components include finance, market (regulation), partnership (particularly public–private partnership), and legitimacy. According to the research results, the characteristics of business concepts related to the diffusion of large-scale environmental technology systems (e.g. large-scale biogas production systems, waste-to-energy and material recycling systems, and waste-to-energy systems) are as follows. Large-scale environmental technology systems need to be complex, require high initial investment, and have legitimacy (this means that environmental regulations must always be met).

The commercialization of large-scale environmental technology systems requires a company's technical capacity to provide additional training for its audience and its economic capacity to support high initial investment (Gonzalez, 2009). Customers of new environmental technologies require technologies that are proven to be reliable such as the stable operation of the system and always meeting environmental regulatory standards (Corvellec & Bramryd, 2012). In particular, good compatibility with existing production systems is an important factor in commercialization success that can appeal to customers in terms of environmental technology (e.g. end-of-pipe technologies and eco-friendly processes) (Mejia-Dugand *et al.*, 2013).

2.2.1.2.3 Conceptual Framework for Technology Commercialization

The author has reviewed previous literature on new product performance and technology commercialization and presented the results of commercialization factors, determinants of the diffusion of environmental innovation, and mechanisms (see Section 2.2.1.2.2). Based on these results, the author proposes a comprehensive conceptual framework for technology commercialization (see Figure 2.2). The conceptual framework proposed in this thesis categorizes factors that affect commercialization by technology, organization, and market characteristics (see Section 2.2.1.2.1).

The “policy” and “regulation” factors presented as important factors in the literature on environmental innovation were further categorized as environment characteristics. Other technology push factors—energy efficiency, product quality, and material efficiency— can be included in the “product superiority” (e.g. high-quality, ease of technology implementation, and meeting customer needs) derived from the previous literature.

Among the factors derived from the environmental technology system diffusion literature (Corvellec & Bramryd, 2012; Kanda *et al.*, 2015), factors other than “policy” and “regulation” were included or added to concepts derived from new product performance and R&D project performance literature. For example, the company's technical capacity to support technical training for customers of environmental technology systems is included in “technological synergy.” The economic capacities of firms that can afford a high initial investment are included in the “resources of money.”

Additionally, the author added the concept of “technology reliability” to technology characteristics to take into account legitimacy, which is one of the most important factors for environmental technology. The legitimacy of environmental technologies can be achieved from the demonstration of their reliability (Corvellec & Bramryd, 2012). Finally, good compatibility with customers’ existing process systems is a product advantage that is included in the “technology superiority” factor.

The concept proposed in this thesis contains 15 factors, of which “uncertainty” and “competition intensity” are negative factors in the success of commercialization. As already mentioned, “uncertainty” leads to time and cost increases at the development and market entry stages (Ragatz *et al.*, 2002). In addition, a high rate of market introduction of new technologies can create strong competition and act as an obstacle to successful commercialization. “First to market” and “uncertainty” were identified as factors influencing radical innovation, but are not excluded from the conceptual framework according to the literature review strategy. The author refers to Section 2.2.1.2.2 for the derivation of concepts from previous literature, the mechanisms between commercialization success and factors, and the characteristics of environmental technologies.

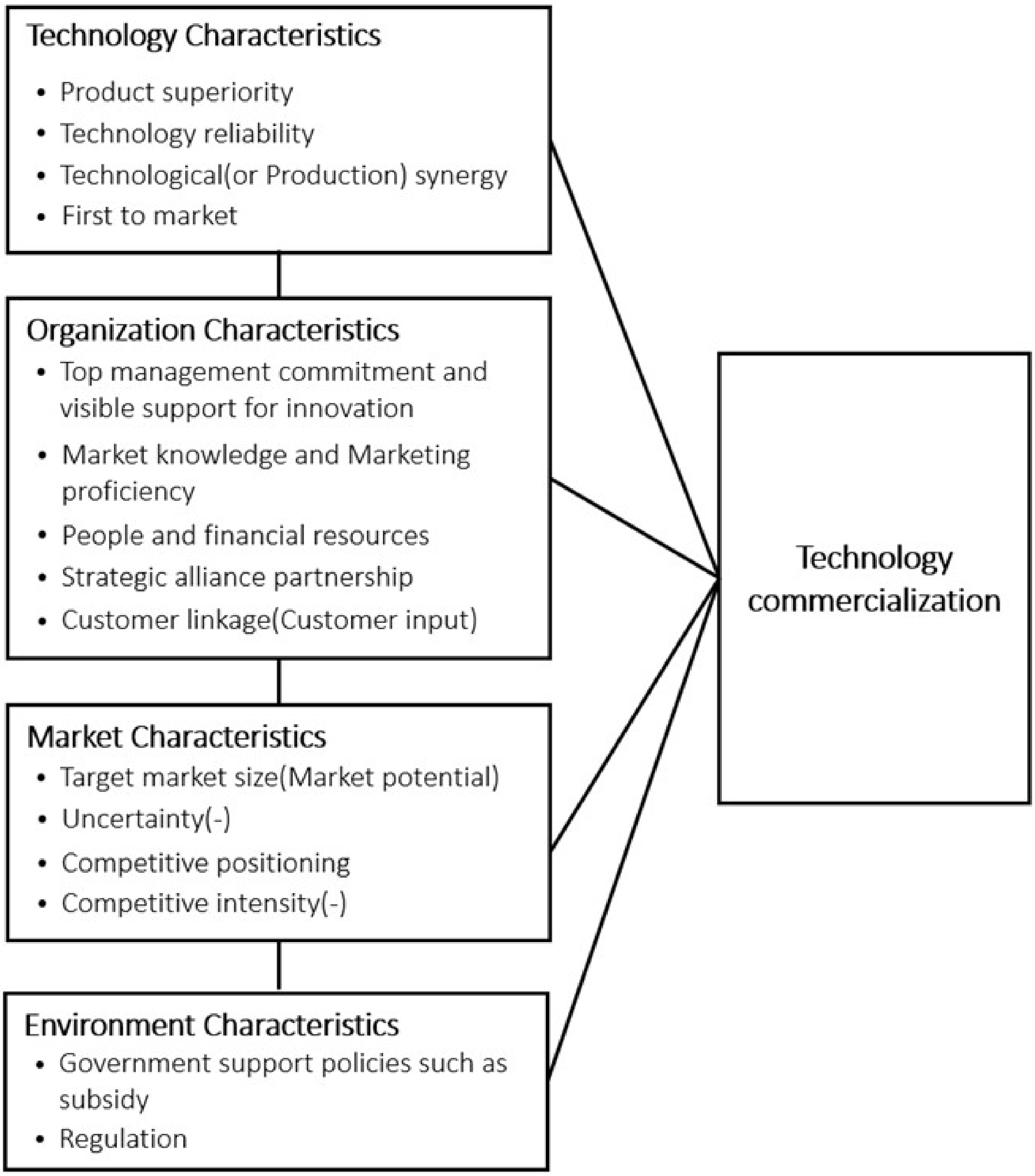
The factors excluded from the conceptual framework of this thesis are: “Innovation culture,” “property rights” (e.g. CEO ownership, fairness of property distribution, and patent scope), "personal characteristics of researchers," and "availability of resources." In previous studies on new product performance, technology commercialization, and eco-innovations, these factors were not recognized as relatively important. First, the "innovation culture" factor is recognized as the commitment and support of members (Galbraith *et al.*, 1991; Radosevich, 1995), and some studies have suggested it as a factor influencing the success of technology commercialization. In most studies (e.g. Voss, 1985; Cooper & Kleinschmidt, 1995a; Ernst, 2002), "culture" is expressed as the "innovation-friendly climate" or "entrepreneurial climate" in an organization. The latter interpretation of "culture" can be understood in the same context as "senior management's recognition" proposed by Ernst (2002).

In the case of SMEs with limited resources, the "senior management's recognition" concept is included in "top management commitment and support." Second, researchers' personal characteristics (Galbraith *et al.*, 1991) and the availability of resources (Balachandra and Friar, 1997) have rarely been proposed as important factors in previous studies. For example, in the main literature review studies (e.g. Montoya-Weiss & Clantone, 1994; Balachandra & Friar, 1997; Henard & Szymanski, 2001; Ernst, 2002; Datta *et al.*, 2015; Kirchberger & Pohl, 2016; Dutta & Hora, 2017), personal characteristics and the availability of resources are rarely mentioned or important.

Finally, property rights-related factors have been proposed as important factors in the technology transfer research of university development technologies (Colyvas *et al.*, 2002) and the performance studies of university startups (Shane & Stuart, 2002). In accordance with the exclusion criteria (see Section 2.1.1) in the literature review of this thesis, literature focused on technology transfer or knowledge transfer have been excluded from the review.

Figure 2.2

Conceptual Framework for Technology Commercialization



The concepts covered in previous studies related to new product performance and technology commercialization frequently use aggregate variables. Even if the same aggregate variable is used, the underlying factors may vary between studies (Balachandra & Friar, 1997). For example, it is unclear what "emphasize marketing" means. In addition, “top management support” can have many different meanings. Accordingly, clear definitions are needed for the individual elements that make up a conceptual framework. The author defined concepts for the factors of the conceptual framework (author, Figure 2.2) and clarified the scope (see Table 2.1).

The conceptual framework and the definition of factors presented in Chapter 2 form the basis of the analytical model of the statistical-quantitative study of this thesis (Chapter 4).

Table 2.1

Factor Definitions

Dimension	Factors	Definitions	References
Technology characteristics	Product superiority	Product differential advantages (for example, a high performance-to-cost ratio, economic advantages (cost–benefit) to the customer), ease of implementation, and enabling previously impossible things	Cooper(1979; 1980), Cooper & Kleinschmidt(1987), Balachandra & Friar(1997), Maidique & Zirger(1984).
	Technology reliability	Evidence of the legitimacy of environmental technology; for example, proven reliability of technology through field test results and operational results.	Kanda *et al.*(2015), Corvellec & Bramryd(2012)
	Technological synergy	Coordination between new technologies of new product development projects and the technological skills existing in an enterprise. Technological skills represent technical engineering, skilled technical and production activities, and holding source technology.	Cooper & Kleinschmidt(1987), Montoya-Weiss & Clantone(1994), Henard & Szymanski(2001)
	First to market	This represents early to market, early market entrants. This is understood as a first-mover advantage based on the uniqueness of a product.	Balachandra & Friar(1997)
Organization characteristics	Top management commitment and visible support	Top management's commitment and support to overcome obstacles to innovation, top management's willingness, economic support from top management (e.g. R&D funding for field-scale testing, third-party verification, and marketing funding for market launch), and top management acceptance of risk.	Rothwell(1992), Ernst(2002), Cooper(1980)
	People and financial	The compatibility of the resource basis of a firm with new project	Montoya-Weiss & Calantone(1994),

Dimension	Factors	Definitions	References
	resources	requirements. For example, sufficient R&D or marketing budgets, access to funding or capital, focused commitment of personnel resources.	Cooper & Kleinschmidt(1996), Martey *et al.*(2017), Montoya-Weiss & Calantone(1994), Henard & Szymanski(2001)
	Market knowledge and Marketing proficiency	Market-oriented activity capabilities; for example, understanding and evaluating customer needs, accurately predicting market potential, and observing competition. The proficiency with which a firm conducts its marketing activities.	Henard & Szymanski(2001), Ernst(2002)
	Strategic alliance partnership	A firm's absorptive capacity-building activities; for example, cooperation with research universities and exchange of research personnel. Cooperation with customers in the R&D stage.	Fabrizio(2009), Dutta & Hora(2017), Walsh *et al.*,(2016)
	Customer linkage (customer input)	Maximize fit with customer requirements (This is also expressed as identification of customer needs).	Datta *et al.*(2014)
Market characteristics	Target market size (market potential)	Strong market presence; for example, market size and market potential.	Cooper(1980), Merrifield(1981), Islei *et al.*(1991), Balachandra & Friar(1997)
	Uncertainty (-)	Potential for unexpected market changes.	Ragatz *et al.*(2002)
	Competitive positioning	Position in the market based on the company's marketing assets and competencies, examples include company reputation, branding, and customer relationships.	Hooley *et al.*(2001)
	Competitive intensity (-)	High market introduction rate of products in the target market.	Cooper(1980), Yoon & Lilien(1985), Maidique & Zirger(1985)
Environment characteristics	Government support policies	Government support programs such as subsidies and venture capital from the government for the	Kemp(1997), Rennings(2000); Watjatrakul(2005)

Dimension	Factors	Definitions	References
		adoption of eco-innovation. R&D subsidy to support enterprise technology innovation.	
	Environmental Regulation	Environmental regulatory standards to drive environmental process innovation.	Kemp(1997), Rennings(2000)

2.2.1.2.4 Dynamics of Technology Commercialization Success

Technology commercialization is a matter of the capabilities of all functions and the balance and coordination between them and cannot be achieved by doing only one or two well (Cooper and Kleinschmidt, 1988). However, Commercialization failure can be caused by a single factor (Cooper and Kleinschmidt, 1988). For example, if "technical competitiveness" or "technical completeness" is not adequate, top management can abandon commercialization. Of course, insufficient "technical competitiveness" and "technical completeness" can negatively affect the results of subsequent marketing activities. Based on the previous literature, the author describes key factors, basic prerequisites, and catalytic factors that can increase the effectiveness of technology commercialization success. This also describes the external factors (market and environment factors) required for technology commercialization. An understanding of dynamics is the theoretical basis of Chapter 5 for qualitative research.

Product superiority is the single most significant and fundamental factor of technology commercialization success. Product superiority integrates unique features for customers, higher quality than competing products (e.g. tighter specifications, stronger, longer-lasting, and more reliable), easier implementation, and helps meet customer needs more than competing products (Cooper, 1979; 1980, Cooper and Kleinschmidt, 1987). In the case of environmental technology, in particular, customer trust in technology derived from legitimacy is one of the most essential and fundamental prerequisites for new product commercialization projects. Environmental technologies must always meet environmental regulations (this is expressed as legitimacy). Customers of new environmental technologies require technologies that are proven reliable such as the stable operation of the system and always meeting environmental regulatory standards (Corvellec & Bramryd, 2012).

Technological synergy can act as a catalyst in improving product superiority and technology reliability. Technological synergy based on technical engineering, production, and resources can support technology development and production activities such as new product design and production processes (Montoya-Weiss & Calantone, 1994). Customer involvement in the development phase can contribute significantly to product improvement through the design of flexible products with respect to user adaptation (Rothwell, 1992). "Customer linkage" can play an important role in improving product superiority in terms of meeting customer needs and improving quality (Henard & Szymanski, 2001). Government support policies such as government support commercial-R&D and infrastructure startups can contribute to product superiority and technological reliability in the new product commercialization process of resource-poor SMEs (Watjatrakul, 2005).

According to the previous literature, successful companies are proficient in market-oriented activities. Such activities include market assessment, market research, test markets, and market launches (Cooper, 1980). For new products to enter the market and expand profits, all competitors' products in the market must be clearly described (Mishra *et al.*, 1996). Successful companies require that companies constantly update market research information (their understanding of customer needs, market potential, market competition) throughout the new product commercialization process.

Firms need huge expenditure on market research and entry into new products (Ernst, 2002). In particular, top management commitment to and visible support (e.g. decision-making of resource input and allocation, and risk acceptance) for resource-poor SMEs can contribute to the persistence of new product commercialization projects. Top management risk acceptance can also play an important role in the commercialization success of innovation (Rothwell, 1992). Senior management support and control positively impact new product performance by contributing to improved efficiency, including product concept effectiveness and process performance (Brown and Eisenhardt, 1995).

Environmental factors include environmental regulations, government-support policies (economic incentive support policies for technology adoption (subsidies), technical support (e.g. public R&D subsidies)). Companies can carry out government-sponsored R&D projects to maintain competitive advantages in the market internally and have internal resources directly related to performance (Watjatrakul, 2005).

Competitive positioning and strategic partnerships in the marketplace can help technology commercialization succeed. Specifically, competitive positioning in the market can help the competitiveness of market offerings based on branding, customer relations, etc. (Aarikka-Stenroos & Sandberg, 2012). Cooperation with research universities can be helpful during the development phase through access to research equipment, personnel exchanges, etc. (Dutta & Hora, 2017). Cooperation in the launch phase with other companies can support NPD success through relational resources (e.g. distribution networks and marketing communications) (Dutta & Hora, 2017).

The presence of market or technical uncertainty can reduce project performance due to complexity (Ragatz *et al.*, 2002). Unexpected uncertainties can negatively impact technology commercialization success; these include poor product quality, increased development time, increased development costs, changes in market demand, and delayed entry to the market. Strong competition in the market can also negatively impact technology commercialization success. New product commercialization project success requires avoiding or overcoming uncertainty and intense competition as much as possible in the new product commercialization process.

2.2.1.2.5 Measurement of Technology Commercialization Success

According to the literature review, financial performance and non-financial performance are generally applied to measure the success and performance of technology commercialization. In an early study in this field, Cooper and Kleinschmidt (1987) measured the performance of technology commercialization with three complex factors: financial performance, opportunity window, and market share. Griffin & Page (1993) classified new product development's success measurement into four areas as shown in Table 2.2 based on surveys of companies and researchers.

Table 2.2

Success Measures in New Product Development

Categories	Measures
Customer-acceptance measures	customer acceptance, customer satisfaction level, met revenue goals, and revenue growth
Measures of financial performance	break-even time from start of project, attains margin goals, attains profitability goals, and internal rate of return or return on investment
Product-level measures	product development cost, launched on time, product technical performance, met quality guidelines, and speed to market
Firm-based measures	hit a window of opportunity, % of sales provided by products less than five years old

Source: Reorganization of Griffin & Page (1993)

In subsequent studies (Todorova & Durisin, 2007; Zahra & Nielsen, 2002; Lichtenthaler & Lichtenthaler, 2009), measures of the technology commercialization performance were reclassified into non-financial (e.g. product innovations, new product marketability, launch rate of new products, and the frequency of launches) and financial dimensions (e.g. revenue, yield, and market shares). Recent deductive-quantitative research in this field suggests one implication. Studies targeting industries in which market entry is difficult early in life (e.g. Dutta & Hora, 2017; Hora & Dutta, 2013; Zhao *et al.*, 2017, Lin *et al.*, 2015) use non-financial performance (e.g. market launch, count of success, and time to new products) as a dependent variable. In addition, many studies have used a project as an analysis unit to determine the success of technology commercialization through "generating sales of developed products, technology" and "market entry" (see Appendix 1).

2.2.2 Methodological Overview of Previous Research

This section examines the methodological characteristics and the scientific purpose of the study through a descriptive analysis for literature on new product performance and technology commercialization over the last five years. The author understands the appropriate methodology of research on new product performance based on the developmental stages of the theory of Edmondson and McManus (2007).[20]

[20] Edmondson & McManus (2007) proposed the following scientific knowledge development stages: Nascent, Intermediate, and Mature.

	Nascent	Intermediate	Mature
Propensity of theory	Propositional/inductive	Potential/integrative	Verifiable/deductive
Theoretical contribution	Discovery and proposal of new concept → Production of theory	Identification of relationships through integration and synthesis between theories → Development of theory	Verification of matured theory through various cases → application of theory
Data analysis methods	Mainly inductive–qualitative research, case study	Mainly meta-analysis, conceptual review	Mainly deductive–quantitative, statistical
Data collection types	Qualitative, initially open-ended data	Hybrid (both qualitative and quantitative)	Quantitative data focused measures

Source: Edmondson & Mcmanus (2007: 1160)

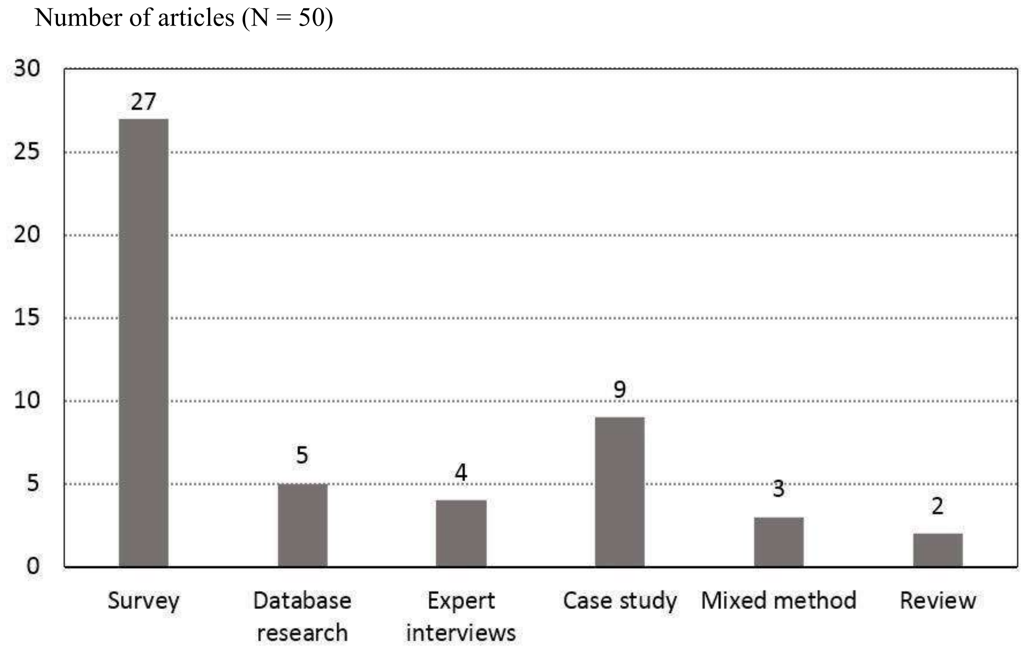
2.2.2.1 Methodologies Applied

The analyzed articles were classified into five methodologies based on the data collection type (see Figure 2.3). Survey research accounts for 41% of the total. All 27 articles were statistical-quantitative studies and they mainly used structural equations and regression analysis. Database research revealed five articles, including Dutta *et al.* (2017), all of which are statistical-quantitative studies. For example, Dutta *et al.* (2017) collected data from the biotech industry from the USPTO dataset. They statistically analyzed the relationship between technology commercialization success and the existence of upstream, downstream alliance. Four articles were found that use the expert interview method, three of which are deductive method articles. For example, the analytical tools used were structural equations (Chen *et al.*, 2014), exploratory factor analysis (Salavati *et al.*, 2016), and an analytical hierarchy process (Yousefi *et al.*, 2017).

Malshe and Biemans' (2014) study of medical devices used a grounded theory method and proposed a relationship between the role of technology commercialization and sales. Case study methods were identified in nine articles. Among them, Sarja (2015) and Fettermann *et al.* (2017) performed deductive-quantitative studies using multi case analysis. Mixed method studies were identified in three articles. One of the articles used a typical grounded theory approach, with the preceding qualitative and subsequent quantitative studies. The other two works specify that the mixed method was applied (for example, exploratory design in which qualitative and quantitative studies are conducted sequentially; Creswell & Clark (2007:85)) but the actual content was confirmed by general statistical-quantitative research in which factors were identified through literature review and then statistical analysis was performed.
Finally, two review literatures were included (Aarikka-Stenroos *et al.*, 2014; Khan *et al.*, 2013) that applied systematic literature review and meta-analysis. In conclusion, 39 articles in the literature (78%) were identified as deductive-quantitative studies. According to Edmondson and McManus (2007), in the scientific knowledge development stage, mature research mainly shows the methodological tendencies of deductive-quantitative research and statistical research.

Figure 2.3

Research Methodologies Employed (2014-2018)



2.2.2.2 Scientific Purpose of Research

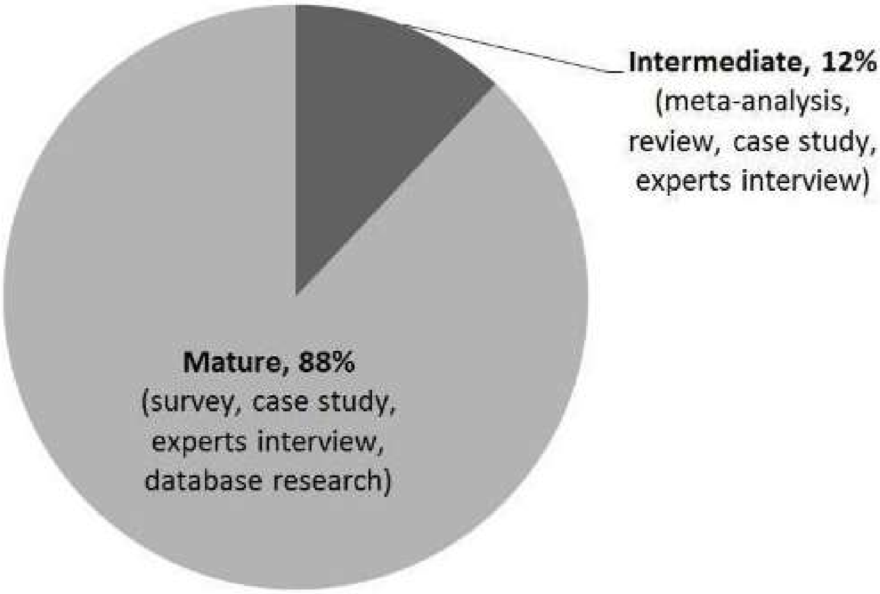
Of the 50 articles in the literature selected for descriptive analysis, 88% (44 articles) were identified as having either verifiable or deductive features. That is, as shown in Figure 2.4, 88% of the investigated articles verify the mature theory by applying it to various cases based on previous theories. Survey studies and database studies test previous theories in various contexts (e.g. high-tech, semiconductor, bio-tech, renewable energy technology, consumer electronic products, and agriculture).

Explanatory variables are selected based on existing theories and the relationship between explanatory variables (e.g. cooperation with external organizations, patents, and organization characteristics in new product development) and technology commercialization (e.g. financial or non-financial success) is statistically evaluated in various contexts. Nine articles applying the case-study method were mostly aimed at an in-depth understanding and description of the subject, rather than the production of theory. They differ in how they were collected and analyzed compared to survey studies. However, the research purpose of verifying existing theories through various cases (e.g. forestry, renewable energy, and ICT) is similar. Some studies (Heng *et al.*, 2014; Farinha *et al.*, 2016; Henttonen & Lehtimäki, 2017) have attempted to identify the relationship between specific issues (e.g. open innovations) and commercial success. These studies, along with meta-analysis and review literature, are categorized as the intermediate stage of scientific knowledge development. Except for Malshe and Biemans (2014), expert interview studies have shown that the goal is to test existing theories and add context. According to Edmondson and McManus (2007), the intermediate study in the development of scientific knowledge aims at the theorization of relations through integration and synthesis between theories. The purpose of studies of maturity research is to test previous mature theories by applying existing theories to various cases.

Figure 2.4

Scientific Knowledge Development Stages (2014-2018)

Number of articles (N = 50)



2.3 Conclusion

The literature review of this thesis aims to understand theories involved in researching new product performance. In particular, it identifies factors presented in previous studies on new product performance and seeks to understand the dynamics of new product development. Recent methodological features in the field of research on new product performance and technology commercialization are reviewed to understand their methodological characteristics.

2.3.1 Theoretical Implications

New product performance research based on various theories (e.g. strategy, organizational theory, operational management, economics theory) focused on explaining and predicting phenomena associated with each sector of industry. In particular, recent studies based on empirical evidence (factors and dynamics) from previous literature have added new cases to existing studies on new product performance and technology commercialization. Although the new product performance research field has been studied by many scholars for over 40 years, it is surprising that there is no “new product development theory” that can provide a comprehensive understanding of the new product performance process. However, there have been attempts to develop new product development process models (or theoretical framework of new product development) that focus on the new product development process (Deshmukh and Chikte, 1980; Brown and Eisenhardt, 1995; Krishnan and Ulrich, 2001). Each highlights specific theories and phenomena within the new product development but does not aim at a comprehensive perspective (Loch and Kavadias, 2008). Moreover, despite the importance of SMEs and environmental technologies for national and sustainable development, and the field of new product performance research being in the maturity stage, there has been little research on the process of commercializing environmental technologies in terms of technology suppliers.

According to literature reviews related to new product performance, new product development research includes management, marketing, entrepreneurship, economics, and strategy. Units of analysis include parts of the new product development process level, enterprise level, and industry level. As such, developing a comprehensive theory of new product development research is very difficult. Understanding the comprehensive new product development process from a technology provider's perspective requires a conceptual framework for technology commercialization that can encompass product, organization, market, and environmental characteristics. This conceptual framework can serve as a foundation of this thesis to obtain comprehensive academic and policy insights into the success or failure of SMEs' commercialization of environmental technologies.

2.3.2 Summary of the Conceptual Framework and Dynamics of Technology Commercialization

The key findings in the literature review of this thesis allow for the construction of a conceptual framework of technology commercialization. The elements of this framework, identified in the review of the literature, consist of internal (technology characteristics and organization characteristics) and external factors (market characteristics and environment characteristics) for the companies implementing new product development. The conceptual framework of new product development proposed by the author of this thesis is composed of 15 factors in four categories: technology, organization, market, and environment characteristics.

Technology commercialization is a matter of the capabilities of all functions and the balance and coördination between them and cannot be achieved by doing only one or two well (Cooper and Kleinschmidt, 1988).

The author of this thesis has found in past literature that product superiority, technical reliability, and market knowledge (or a company's market research capabilities) are key factors for technology commercialization success. In particular, technology reliability can be one of the most important factors in terms of environmental technology-related new product development as it includes the legitimacy to meet environmental regulatory standards at all times.

In terms of the commercialization of environmental technologies, government economic incentives (e.g. electric vehicle subsidies and eco-friendly boiler subsidies), and stricter environmental regulations can increase the potential of technology commercialization success in environmental technologies by growing environmental markets. In the environmental technology sector, government policies and regulatory factors can affect the target market size.

Technological synergy, top management commitment and visible support, customer linkage (customer input), and government support policies (e.g. government support commercial-R&D, infrastructure startups) have been identified as factors that can contribute to improved product superiority and technical reliability. Resource-poor SMEs can improve their product superiority including product quality improvements, follow-up R&D, and performance verification based on government support policies. Technological synergy can contribute to shortening product development and production preparation times and improving quality during product development and production. Customer linkage can contribute to product quality improvements during product development preparation and execution. Other factors such as sufficient resources, strategic alliance partnerships, and early to market that are based on product uniqueness can contribute to increasing the probability of technology commercialization success throughout the new product development process or during the launch phase.

2.3.3 Methodological Implications

According to Section 2.2.2 in this thesis, recent research in this field has been largely composed of statistical and deductive studies based on surveys. Specifically, recent research in this field (e.g. Morgan *et al.*, 2015; Lin *et al.*, 2015; Eling *et al.*, 2013; Rese *et al.*, 2016; Jo & Park, 2017) has focused on supplementing the rigor of statistical aspects (e.g. the use of structural equations or mediator variables). These studies can support relatively strong reasoning by adding a mediator variable in the path analysis based on structural equation models. Mediator variables can analyze the indirect effects of one variable on another through its mediator. Technology commercialization research in the field of environmental technology has only rarely been covered in past research. Therefore, there is insufficient empirical evidence to use the structural equation; even if the statistical methodological complements were rigorous, understanding the process by which environmental technology can be successfully commercialized is difficult.

In addition, although not addressing the limitations of previous statistical studies in this area (e.g. survey respondents, sample size, statistical validity, reliability verification), a new approach is needed to gain a comprehensive understanding of SMEs' environmental technology commercialization. The mixed-method research design provides a way of dealing in depth with the context of the situation surrounding the phenomenon (Greene *et al.*, 1989; Bryman, 2006; Creswell & Clark, 2011). The convergent parallel mixed-method design can improve the validity of the research results by simultaneously conducting statistical-quantitative and qualitative research and comparing and contrasting each result. In addition, an understanding of the interrelationships between success factors (mechanisms) can provide deep insights into SMEs' commercialization of environmental technologies.

CHAPTER 3: RESEARCH DESIGN

3.1 Overview

According to the literature review in this thesis (Section 2.3.3), recent research on new product performance and technology commercialization includes a large number of statistical and deductive studies based on surveys and supplements the research validity through the application of strict statistical methods such as the use of structural equations. However, research on commercialization performance in the field of environmental technology has rarely been attempted in academic and policy studies. Therefore, understanding the factors and mechanisms in the new product development process of environmental technology requires complementary research methods in addition to statistical-deductive studies. This thesis applies a mixed-method study design. Specifically, a convergent parallel mixed-method design is applied and quantitative and qualitative studies are conducted simultaneously; the results are verified or complemented by comparing and contrasting. Comparing and contrasting individual findings can increase their validity and understanding the mechanisms and dynamics of success can provide deep insights into SMEs' commercialization of environmental technologies. This section introduces an overview of mixed-method research and explains the advantages of mixed methods, the philosophical assumptions of convergent design, and the overall visual model of this thesis.

3.2 Characteristics of Mixed-methods Design

The comprehensive research method in this thesis is a mixed-method study (Creswell & Clark, 2007; 2011). Specifically, it is expressed as a convergent parallel mixed method that collects and analyzes quantitative and qualitative data separately and combines the results within a single study (Creswell & Clark, 2011; Tashakkori & Teddlie, 1998). Convergent parallel designs can provide a more complete understanding of the research question through simultaneous quantitative and qualitative studies (Creswell & Clark, 2011). For the same case, the validity of findings can also be demonstrated in terms of existing theoretical verification through mutual comparison and contrasting between simultaneous quantitative and qualitative findings. Qualitative research can provide a broad understanding of the situational context and the dynamic aspects of technological commercialization. The mixed-method design provides an in-depth way to deal with the complexity and diversity of the context and problems surrounding the phenomenon (Greene et al., 1989; Bryman, 2006; Creswell & Clark, 2011).

The rational basis for integrating the results of quantitative and qualitative research in this thesis can be found in the reasons and advantages of applying the mixed-method design proposed by Bryman (2006) (see Table 3.1).

Table 3.1

Reasons to use the Mixed-methods Design

Validity	Quantitative and qualitative studies can be combined to triangulate the results to complement each other.
Offset	Quantitative and qualitative research has its own strengths and weaknesses; by combining them, researchers can offset weaknesses and derive two strengths.
Completeness	Adoption of both quantitative and qualitative research can bring a more comprehensive account of the area of inquiry of interest.
Credibility	Using both approaches improves the integrity of results.
Enhancement of results	Quantitative and qualitative results can be gained or reinforced by gathering data using qualitative and quantitative research approaches.

Source: Bryman, 2006

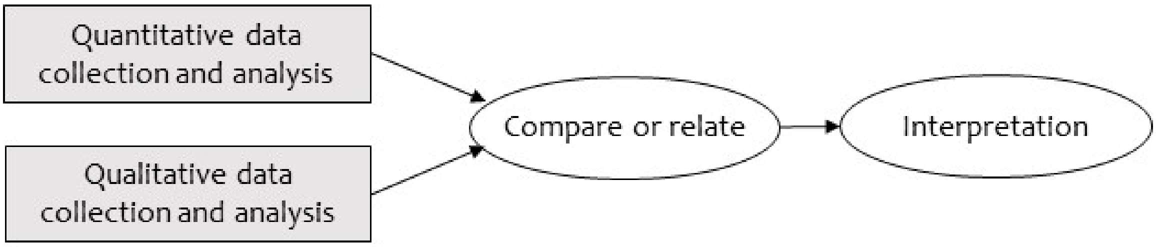
Three factors (priority, timing and integration) must be considered while designing mixed-method research (Creswell & Clark, 2011). The priority, timing, and integration in the mixed-method design of this thesis were considered as follows: the quantitative and qualitative research in this study have equal priority and play an equally important role in solving research questions. The convergent parallel design of this thesis implements quantitative and qualitative studies at the same stages and simultaneous timing of the research process—thus maintaining directionality independently during analysis—and then integrates the results throughout the entire analysis (Creswell & Clark, 2011).

3.3 Mixed Methods; Convergence Parallel Design

This thesis applies a convergent parallel mixed-method design (Creswell & Clark, 2011, Tashakkori & Teddlie, 1998) where quantitative and qualitative studies are performed simultaneously. The author collects both quantitative and qualitative data simultaneously and analyzes each data type separately using existing techniques. Then, the results are displayed and interpreted through mutual comparison and contrasting. This method is mainly used when researchers need to directly compare and contrast statistical quantitative and qualitative results to interpret abundant results through corroboration, verification, and complementation. (Creswell & Clark, 2011). Figure 3.1 shows a conceptual diagram of the convergent parallel design.

Figure 3.1

Prototypical Version of Convergent Parallel Design



Source: Creswell and Clark, 2011, p. 69

In theory, the convergent parallel method design has several advantages (Creswell & Clark, 2011, p. 78). By obtaining different supplemental data on the same subject, the research question can be best understood (Morse, 1991). The strengths of quantitative methods (e.g. large sample size, trends, and generalization) and the strengths of qualitative methods (e.g. small sample, details, and in-depth) can be used to compensate for the weaknesses of individual methods (Patton, 1990).

Convergent parallel design can be an issue regarding the philosophical assumptions of research. Creswell and Clark (2011: chapter 3, p. 78) commented on the philosophical assumptions of convergent parallel design; regarding mixed-method studies, the philosophical assumption of convergent design is most appropriate for the "umbrella" paradigm such as pragmatism. The assumptions of pragmatism are well-suited to guiding the work of merging the two approaches into a larger understanding.

Figure 3.2.

Visual Model for Convergent Parallel Mixed-method Flowchart

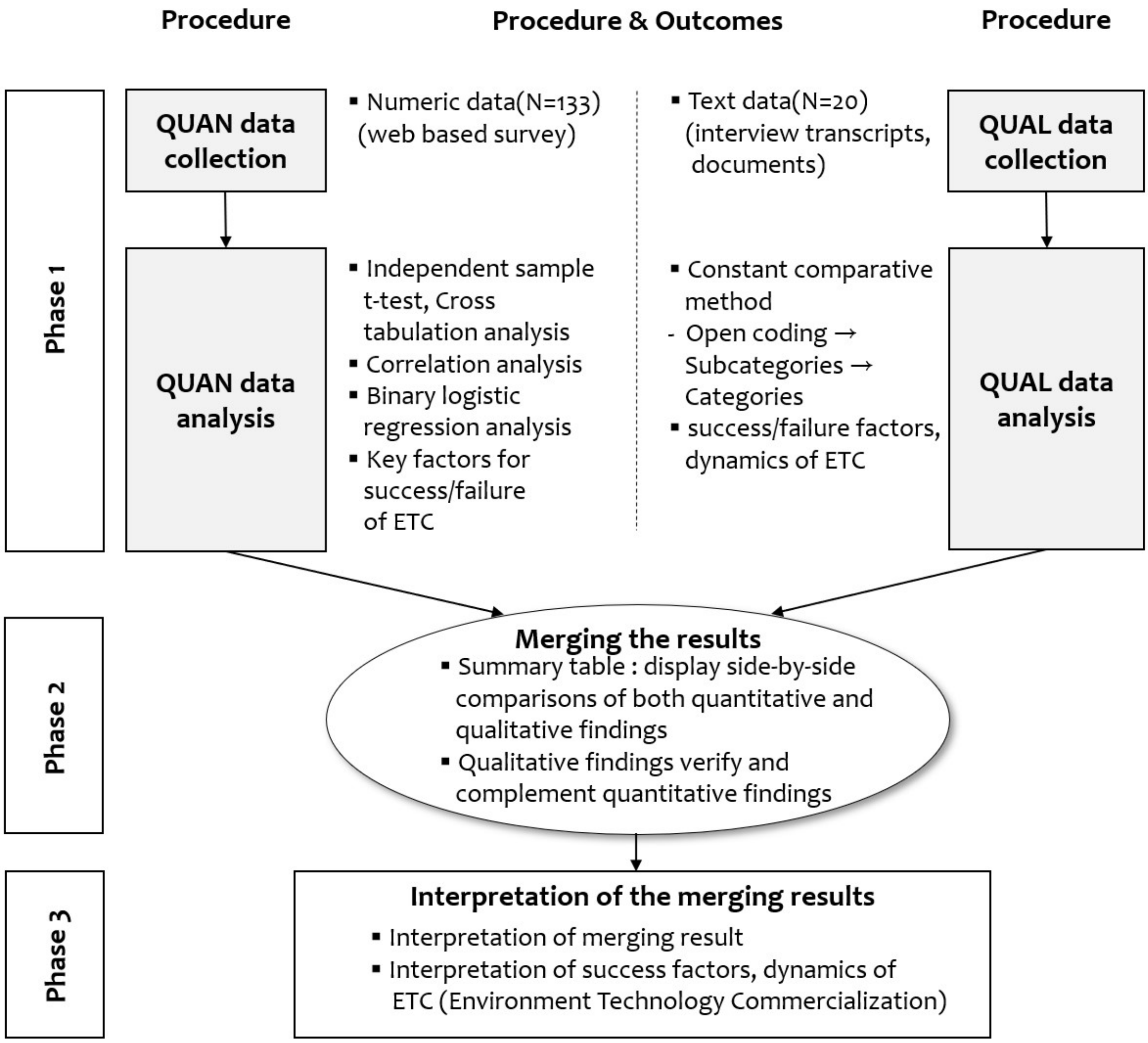


Figure 3.2 shows the overall design of this thesis.

In its first stage, this thesis carries out quantitative and qualitative research simultaneously. Quantitative research uses web-based surveys to collect quantitative and numerical data and analyze them statistically. The quantitative study identifies which factors influence SMEs' commercialization of environmental technology. In addition, the conceptual framework derived from the literature review in Chapter 2 (see figure 2.2) is theoretically verified. In Chapter 4, the conceptual framework was the basis for the quantitative research design (variable selection, analysis model, and hypothesis) and some variables were subdivided into sub-concepts based on factor definitions (Table 2.1). Binary logistic regression was used for statistical analysis.

In the quantitative study of this thesis, the author identifies and corrects multicollinearity through correlation analysis. The aggregate variables have been frequently used for the factors of success proposed from past studies related to new product development (Balachandra & Friar, 1997; Ernst, 2002). In Chapter 2 of this thesis, the author has clarified the definition and scope of the factors that make up the conceptual framework. Nevertheless, multicollinearity can occur when variables have a strong relationship with each other.

In qualitative research concurrent with quantitative research, text data is collected through unstructured interviews and documents. The collected qualitative data is analyzed using the constant comparative method (Maykut & Morehouse, 1994). Basically, the results of qualitative research are the same as those of quantitative research. However, in addition to identifying the influencing factors for environmental technology commercialization, qualitative research provides additional information on the dynamics of environmental technology commercialization. This advantage may be a feature of this thesis compared to the existing literature.

The merging stages of this thesis complement each other by comparing and contrasting quantitative and qualitative findings (convergent parallel design uses the term "merging" according to Creswell and Clark (2011), Tashakkori and Teddlie (1998), but execution complements the results of each study through a method of comparing and contrasting). The comparing and contrasting at the merging step is used with side-by-side comparison (Creswell & Clark, 2011) and displayed with reference to the summary table of Li *et al.* (2000) (Creswell and Clark, 2001, p. 225).

In the final phase, the author interprets the merging results. The research questions in this thesis will be answered through a convergence step.

Chapters 4 (quantitative research) and 5 (qualitative research) describe the detailed study design of quantitative and qualitative research.

3.4 Target Population

This thesis is aimed at SMEs[21] which participated in government-funded R&D projects in

[21] In Korea, the criteria for judging SMEs that are targeted for SME promotion policies include economic scale

the field of the environment. Government-funded R&D projects are the applied research stage of R&D projects aimed at commercialization (see Section 1.1). Participants in this research are small- and medium-sized enterprises that have successfully developed technology (i.e. projects which were deemed a success in the final evaluation of the government program) in the applied research stage R&D project of Environmental Technology Development Program in South Korea. The target population was considered for consistency in the empirical context of this thesis, for representativeness of the sample[22], and for the accessibility of basic information at the early stage of the study. Basic information (e.g. the company's basic information, the project's technical success, the technology's classification and contents, and the performance of commercialization after development) about the projects involved in the Environmental Technology Development Program was collected from a follow-up report of the government-funded R&D program. R&D projects participating in the Environmental Technology Development Program were selected, evaluated and managed according to the project management standard process of the national R&D program. In particular, project planning to selection takes about 12 months and the evaluation items at the selection stage include development plans and commercialization plans.

Criteria for participant selection in this study included: (1) the applied research stage R&D project; (2) projects that have been judged successful in the final evaluation; (3) projects that have passed at least two years since the end of R&D; (4) projects in which research institutes or participating companies are SMEs. In total, 217 projects met the participation criteria. Among these, there are 195 projects excluding those of large companies and 133 projects were involved in quantitative research. The characteristic information for these 133 projects participating in quantitative research and 20 projects participating in qualitative research (participants in qualitative research were selected from within the 133 projects) are described in Chapters 4 (quantitative research) and 5 (qualitative research).

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and corporate independence (e.g., holding company, subsidiary, etc.). Economic scale criteria vary by industry. The environment-related sectors are included in the scope of small and medium-sized enterprises if the company's three-year average sales are approximately ≤$ 45~80 million USD. Sales include both parent and subsidiary sales.

[22] At the applied research stage, the Environmental Technology Development Program accounts for >80% of a country's total R&D budget for the environmental sector.

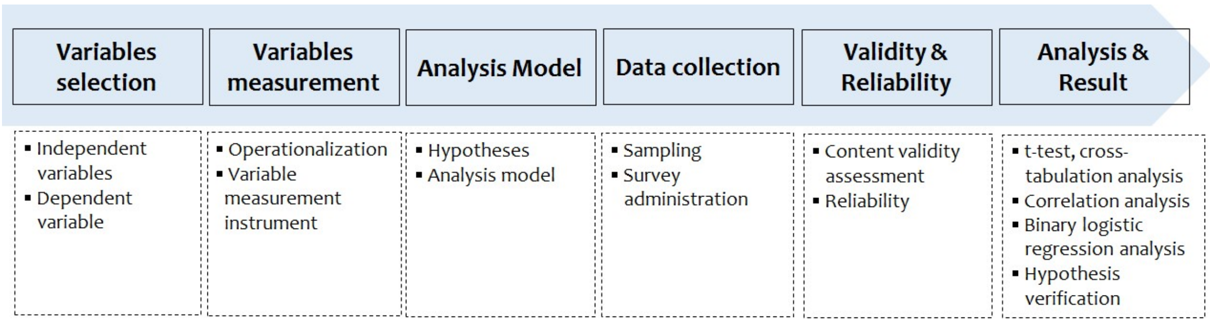
CHAPTER 4: Quantitative Analysis

4.1 Methods and Procedure

Through quantitative research, the author identifies which key factors influence the success or failure of technology commercialization in the context of SMEs' environmental technology. The author selected dependent and independent variables for statistical-quantitative studies based on the conceptual framework (Figure 2.2). Tools for measuring variables have been developed based on the measurement items developed in previous research in this field. The content validity of the measurement tools was reviewed by experts such as professors in technology commercialization and the management of environmental SMEs. Binary logistic regression was used for statistical analysis and multicollinearity check was confirmed through independent variable correlation analysis to increase the reliability of the regression analysis results. Figure 4.1 shows the procedure of the statistical-quantitative study.

Figure 4.1

Quantitative Research Progress Procedures



4.1.1 Selection and Operationalization of Variables

4.1.1.1 Variable Selection

Variables for understanding the research question ("Which factors influence the commercialization of environmental technologies by SMEs?") were previously determined in Chapter 2 of this thesis. The author presents a comprehensive set of technology characteristic, organization characteristic, market characteristic, and environment characteristic variables that are expected to affect the success or failure of commercialization in the theoretical framework section of Chapter 2. Among the derived variables, some of the high concept variables were subdivided into sub-concepts based on the concept definition (see Table 2.1).

4.1.1.1.1 Dependent Variables

According to the literature review in this thesis, the judgment on the success/failure of technology commercialization is mainly determined by the financial and/or non-financial performance factors (Todorova and Durisin, 2007; Zahra and Nielsen, 2002; Lichtenthaler & Lichtenthaler, 2009). In this study, dependent variables used binary variables such as the success and failure of technology commercialization, which are mainly used in this field. For example, financial performance is determined by the amount of revenue generated or the revenue generated by technology developed through new product performance research. In addition, non-financial performance is determined by the frequency, success rate, and market entry of developed technologies (see Chapter 2, Section 2.2.1.2.5, and Appendix 1). In conclusion, in this quantitative study, the success of commercialization refers to the case of market entry and sales generated.

4.1.1.1.2 Independent Variables

In Chapter 2 of this thesis, the author presented a conceptual framework for technology commercialization by reviewing the literature on the diffusion of eco-innovation, new product performance, and technology commercialization (see Figure 2.2). The success or failure factors proposed in the conceptual framework (see Figure 2.2) are applied as variables in the statistical-quantitative research in this thesis. Some concepts were subdivided into sub-concepts during the definition of the concept (see Table 2.1). Each independent variable is described using four categories: technology characteristics, organization characteristics, market characteristics, and environment characteristics.

▪ **Technology Characteristics**

The variables included in the technological characteristics have been copied from the conceptual framework (Figure 2.2). In quantitative research, the independent variables related to technological characteristics are “product superiority,” “technology reliability,” “Technological synergy,” and “first to market.”

▪ **Organization Characteristics**

Among the variables included in organization characteristics, those taken from the conceptual framework are: “top management commitment and support,” “market research skill” (also referred to as market knowledge in the conceptual framework), “marketing proficiency,” and “identification of customer needs” (also described as customer input in the conceptual framework).

Other concepts were subdivided into sub-concepts based on the clarification of meaning, clarity of coverage, and ease with which variables are measured (Balachandra & Friar, 1997). The setting of the sub-concept is based on the factor definitions of the literature review (see Table 2.1). “Human resources” can be classified as “human resources dedicated to R&D” and “human resources dedicated to marketing” (Henard & Szymanski, 2001). “Financial resources” can be classified as “sufficient R&D funding,” “sufficient marketing funding” and “financial accessibility” (in the literature, this is expressed as access to funding or capital) (Montoya-Weiss & Calanton, 1994; Ernst, 2002). “Strategic alliance partnership” is classified into various sub-concepts including “R&D collaboration” and “cooperation with customers” (also described as vertical collaboration) (Walsh *et al.*, 2016).

▪ **Market Characteristics**

Variables included in the market characteristics have been copied from the conceptual framework (Figure 2.2). In quantitative research, independent variables related to market characteristics are “target market size,” “uncertainty,” “competitive positioning,” and “competitive intensity.”

▪ **Environment Characteristics**

Environment characteristics include “government policy” and “regulation.” These factors reflect the conceptual framework of this thesis. In particular, environmental regulation factors are subdivided into various sub-concepts such as “relevance to environmental regulations” and “level of environmental regulations” (Cleff & Rennings, 1999a;b).

4.1.1.2 Operationalization of Variables

The overall structure of the questionnaire was designed through an in-depth review with experts (e.g. project evaluation committee and operators of government-supported R&D program) and enterprise project managers (e.g. participants in this thesis's quantitative research) with core competencies in the field of environmental technology and technology commercialization. The specific operationalization was based on the measurement tools and measurement items of existing research in this field. The main statistical-deductive studies (e.g. Cooper & Kleinschmidt, 1987; Song & Parry, 1997; Ragatz *et al.*, 2002; Zahra & Nielsen, 2002; de Sousa Mendes & Devós Ganga, 2013; Tepic *et al.*, 2014) in this field consist of questionnaires using multi-item scales and Likert scales.

The quantitative study in this thesis was designed as a single item measurement method, based on sub-concepts derived from the literature review. Specifically, the nominal and Likert scales were used together (see Appendix 2; Item list and measurements). The measurement results of the nominal scale can be used for regression analysis using dummy variables (i.e. 1 or 0). In this study, the nominal scale was only adopted for factors that could be cross-checked with secondary data (e.g. government-funded R&D project management database and follow-up report). Cross-checking can help the data be measured closer to real phenomena. Measurement tools are described by classifying them into technology characteristics, organization characteristics, target market, institutional environment characteristics. Respondents were asked to respond to projects in the Environmental Technology Development Program (i.e. the applied research stage government-supported R&D program). Respondents were company representatives or project managers involved in projects from the idea-generation stage. Prior to data collection, pilot studies were conducted on some study participants. As a result, there were minor revisions such as the addition of supplementary explanation of measurement items (for example, a detailed description of environmental regulations or environmental standards) and text revisions.

Judgment on the success or failure of the technology commercialization for a number of studies, the project of which is the unit of analysis, can be determined through financial and non-financial performance (see Appendix 1). In this study, the success of technology commercialization is operationalized as "market introduction and new sales generation." Operationalization is based on measurement items from previous research in this field (in particular, the author applied a copy of the measurement items from the source study in Table 4.1, taking into account the definition and scope of the concept in this study).

Table 4.1

Operationalization of Variables

D.	Variables	Measurement	Sources
-	Project performance (dependent variable)	Market introduction and new sales	Zahra & Nielsen, 2002; Todorova & Durisin, 2007; Lichtenthaler & Lichtenthaler, 2009
T	Product superiority	Level of technological competitiveness (e.g. consumer economic benefits, strong performance, ease of implementation, and price competitiveness)	Cooper & Kleinschmidt, 1987; Montoya-Weiss & Calantone, 1994; Song & Parry, 1997; Danneels & Kleinschmidt, 2001; de Sousa Mendes & Devós Ganga, 2013; Rese & Kutschke, 2016.
	Technology reliability	Evidence of the legality (e.g. field-scale tests, operation performance, and third-party verification)	
	Technological synergy	Holding technical resources and skills (e.g. engineering, source and complementary technologies, and related patents) related to development technology	
	First to market	The existence of alternative and competitive technologies in the target market	
O	Top management commitment and visible support	Level of top management commitment to and visible support (e.g. subsequent technology development investment and commercialization investment) to new projects	Martey *et al.*, 2017; Yeh, Pai, & Liao, 2014; Yam *et al.*, 2004; Park & Ryu, 2015, Cooper & Kleinschmidt, 1987;1995; de Sousa Mendes & Devos Ganga, 2013; Ahuja, 2000; Dutta & Hora, 2017; Robinson & Stuart, 2007.
	Market research skills	Level of a firm's market research capability (e.g. market assessment, market research, potential survey, and market competitiveness survey)	
	Marketing proficiency	Commercial experience with similar technologies or systems	
	Human resources dedicated to R&D	Percentage of professional personnel dedicated to R&D	
	Human resources dedicated to marketing	Level of retention of professional dedicated marketing personnel	
	R&D funding	Level of funding for subsequent R&D after government-funded R&D project	
	Marketing funding	Level of funding for the commercialization of development technology	
	Financial	Accessibility to funds required for the	

D.	Variables	Measurement	Sources
	accessibility	commercialization of developed technologies (internal, government, and private)	
	Identification of customer needs	Level of understanding of the needs of the company's customers in the process of technology development and commercialization	
	R&D collaboration	Cooperation with external organizations (e.g. research universities and public-side research institutes) in the technology development process	
	Cooperation with customers	Cooperation with or participation of customers in the development of new products	
M	Target market size	Market potential level of the target market (market strength/attraction)	Cooper, 1979; Cooper & Kleinschmidt, 1987; Song & Parry, 1997; Hooley & Broderick, 1998; Ragatz *et al.*, 2002; Ring *et al.*, 2005; Frederick & Kuratko, 2010.
	Uncertainty (market, technology)	Degree of uncertainty (complexity of technology and market) in the development and commercialization of new technologies	
	Competitive positioning	Level of competitive position of the company as perceived by the customer in the target market related to the development technology (e.g. company reputation, branding, customer relationship, and degree of customization)	
	Competitive intensity	Level of competition intensity in target markets related to technology development	
E	Government support policies	The company has benefited from the government's support policies (e.g. subsequent R&D funding, commercial funding, and subsidies for technology adoption)	Horbach *et al.*, 2012; Rese & Kutschke, 2016.
	Relevance to environmental regulations	How relevant are development technologies to environmental regulation responses?	
	Level of environmental regulations	Level of environmental regulation associated with development technology	

Dimension: T (Technology characteristics), O (Organization characteristics), M (Market characteristics), E (Environmental characteristics)

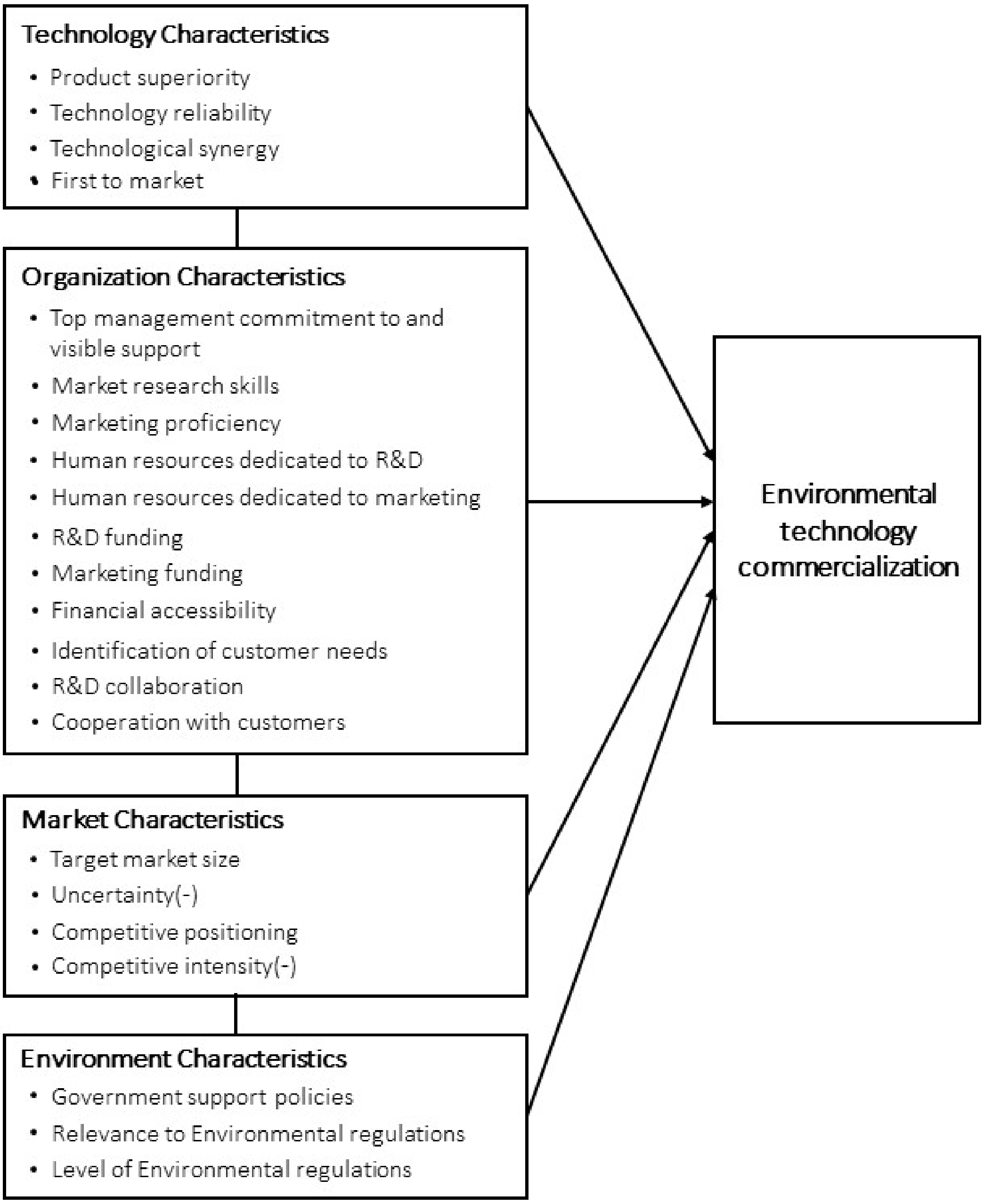
4.1.2 Research Model and Hypothesis

4.1.2.1 Research Model

The author set up a research model for statistical-quantitative research that aimed to identify what key factors affect technology commercialization in the context of the environmental technology of SMEs (see Figure 4.2). As mentioned in Section 2.3, a comprehensive understanding of environmental technology commercialization from a technology supplier's perspective requires the application of variables that can cover the proposed factors from existing studies in this field. Accordingly, 22 independent variables were selected for the statistical analysis of this thesis: four variables in the technology characteristics, 11 variables in the organization characteristics, four variables in the market characteristics, and three variables in the environment characteristics. This research model presupposes the relationship between independent and dependent variables. The independent variable uses quantitative data and the dependent variable uses binary data. In the case of existing statistical-deductive studies in this field (e.g. de Sousa Mendes & Devós Ganga, 2013; Tepic *et al.*, 2014), the available analytical method in this case is binary logistic regression.

Figure 4.2

Analysis Model



4.1.2.2 Setting up a Research Hypothesis

The author set up research hypotheses for statistical-quantitative studies according to the analytical models.

Hypothesis 1. The proposed technology characteristics positively affect the commercialization of SMEs' environmental technologies.

Hypothesis 2. The proposed organization characteristics positively affect the commercialization of SMEs' environmental technologies.
Hypothesis 3. The proposed market characteristics positively affect the commercialization success of SMEs' environmental technologies. However, “uncertainty” and “competitive intensity” negatively impact commercialization of SMEs' environmental technologies.
Hypothesis 4. The proposed environment characteristics positively affect the commercialization of SMEs' environmental technologies.

4.2 Quantitative Data Collection

4.2.1 Sampling

The “target population” of this study is SMEs who participated in the Environmental Technology Development Program (the applied research stage government-sponsored R&D programs in the environmental field). One hundred and ninety-five projects were selected (see the selection criteria in Section 3.3). In this study, there was no sampling and all 195 projects were investigated.

4.2.2 Survey Administration

In the quantitative research of this thesis, the survey method used a cross-sectional survey design. This survey method investigates the state of the present time point and studies the correlation between variables. The questionnaire was distributed and collected over the web and via e-mail.

Data collection took place from December 2016 to early 2018. A three-phase follow-up sequence (Dillman, 2000) was initially used to obtain a high response rate. Cell Phone text messages were sent to participants who had not responded by the set date. After 4–6 weeks, cell phone texts and emails were resent. Finally, participants who did not respond were asked to participate by phone. To reduce the response rate error due to the long data-collection period, in the case of the initially collected questionnaire, the data related to the dependent variable before the end of the survey was updated with the latest data via telephone and e-mail.

In total, 133 projects participated in the questionnaire out of 195 projects, which means that the response rate was 68.2%. While this could be considered 127 companies because six companies participated in duplicate government-supported R&D projects, the study included all 133 projects because the unit of analysis in this study is the project, the survey respondents were different, and the technology was differentiated. Sixty-two projects (60 companies) did not respond to the survey. According to a government-funded R&D follow-up report with the secondary data from the quantitative study, eight projects in the non-participating group submitted revenue for development technology. Table 4.2 shows the status of commercialization for the group that did not participate in the survey.

Table 4.2

Status of Technology Commercialization in the Non-response Group

	Revenue generation	**Not proceeded**	**In progress**	**Total**
Number of cases (N)	8	40	14	62
Ratio (%)	13	64	23	100

Since the end of government-sponsored R&D, 64% of projects have not proceeded to commercialization. The reasons for not commercializing were identified as organizational and market-related issues. The organizational issues include management difficulties and lack of additional skills development, subsequent R&D funding, or commitment. In terms of market issues, reasons such as changing target market conditions, shrinking environmental markets, and the absence of markets were presented. As with previous statistical-quantitative research related to new product performance, the problem of low participation rate in projects that failed to commercialize also appeared in the quantitative study for this thesis. Problems with case selection can lead to distortions of statistical output. However, the weaknesses of quantitative research that can be caused by case selection can be complemented through qualitative research conducted simultaneously in the first phase of this thesis. The status, according to the classification of environmental technology of the group who did not participate in the study, is shown in Figure 4.3 and the result is similar to the status of the participant group (see Figure 4.4). For example, in both Figures 4.3 and 4.4, air-quality management, water-quality management, and waste management/resource recycling account for 71% of the total.

Figure 4.3

Environmental Technology Field Distribution Chart for the Non-response Group

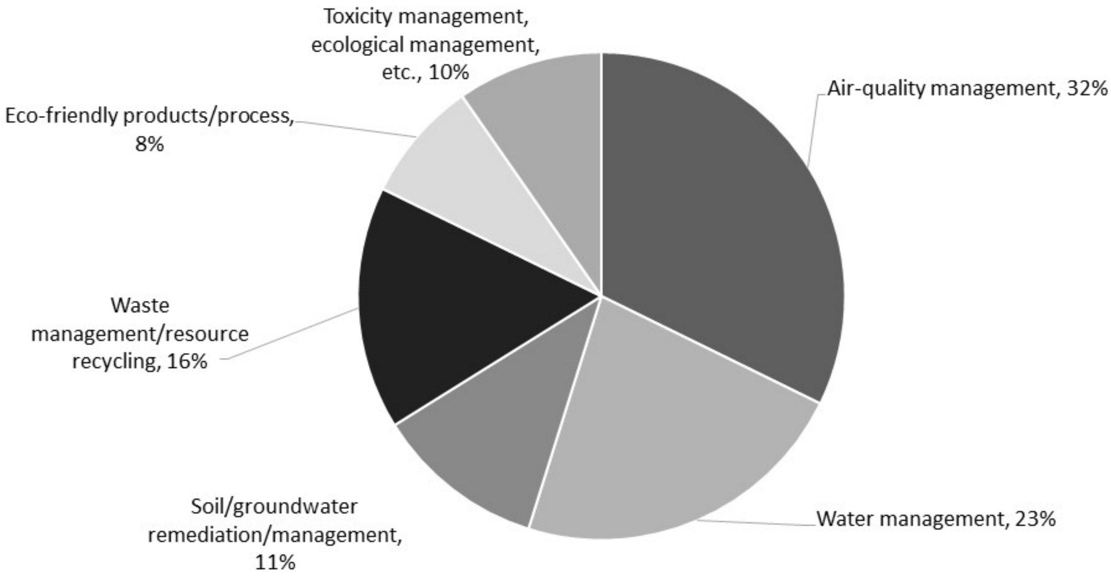


Table 4.3 shows the technology commercialization status of the groups participating in this study. Of the 133 projects participating in this study, 38% succeeded in technology commercialization, 47% failed, and 15% were in progress.

Table 4.3

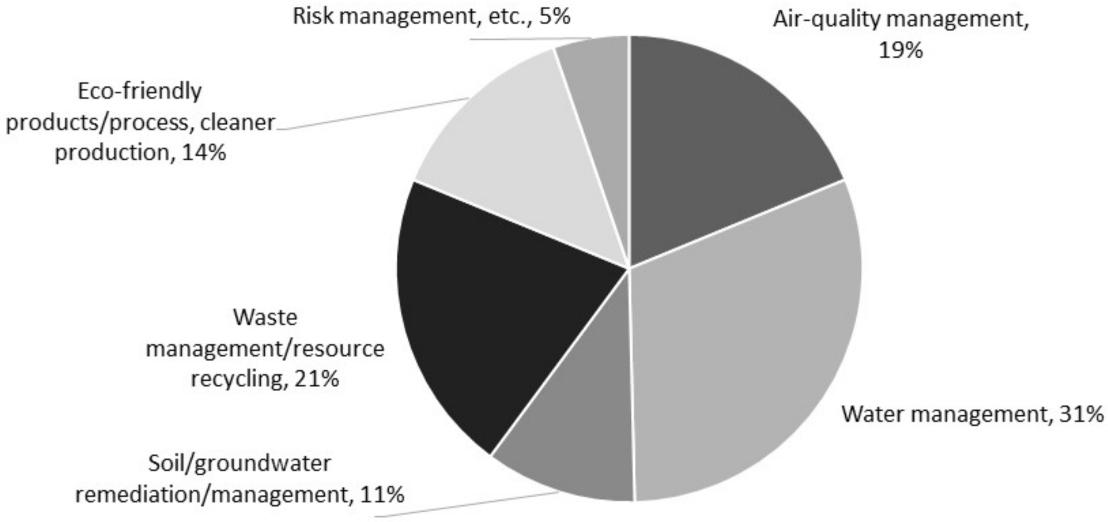
Status of Technology Commercialization in the Participant Group

	Success	Failure	In progress	Total
Number of cases (N)	51	62	20	133
Ratio (%)	38	47	15	100

Figure 4.4 shows the distribution according to the environmental technology classification of the participant groups. There are 94 projects in the water, air, and waste sectors, accounting for 71% of all projects. The distribution according to the environmental technology classification of the participant group tends to be almost the same as the market size of major environmental sectors in South Korea (see Figure 1.4). The case choices in this quantitative study reflect some of the real market situation. The status of projects involved in quantitative research reflects the situation in Korea's environmental market.

Figure 4.4

Environmental Technology Field Distribution Chart for the Participant Group



4.2.3 Validity and Reliability

In the quantitative research, the instrument's validity was verified by the content validity (Heale & Twycross, 2015). In this study, five experts were gathered to review the content validity. The expert group included professors in technology commercialization, project managers in participating companies, and government-supported R&D project operators. Content validity was examined to determine how well measurement items explained the concepts and whether the basis of the previously developed items was correct. As mentioned in the operationalization section of the independent variable, the questionnaire in this study was designed as a single measurement item based on the sub-concept of the previous study. In addition, the author used nominal and interval scales to improve the accuracy of the collected data. Therefore, statistical validations of construct validity and criterion validity were excluded from this study. The use of a single measurement item did not require an internal consistency review (e.g. Cronbach's alpha) to confirm the data reliability. The independent sample t-test and cross-tabulation analysis were conducted before the regression analysis to ensure reliability of the regression analysis results. Multicollinearity was identified and corrected through correlation analysis.

4.3 Results

4.3.1 Characteristics of Participating Firms

The characteristics data of the companies that participated in the quantitative research for this thesis were collected from the official government support R&D program management database and the firm credit information web database. Table 4.4 shows the characteristics of the companies that participated in quantitative research. Regarding the firms' age, 67.1% were 10–20 years old and most were mature SMEs rather than new venture companies.[23] According to Covin *et al.* (1990) and Zahra (1996), it takes 8–12 years for a company to mature, depending on its industrial environment. The average number of employees was 32.6, those with 10–50 people accounted for 57.9% of the total.

Among the participating companies, venture companies focused on research and development may have relatively few employees, even if they are included in the category of SMEs. In addition, 86.7% of the participating companies were rated B or higher. According to the definition of a general credit rating, it is judged that grade B or higher is suitable for investment. The average annual sales amount for the participating companies is $9.9 million USD; the standard deviation is $14.5 million USD and the difference between the minimum and maximum is $75.7 million USD. For firms with major products such as wastewater treatment facility construction, air pollution prevention facility construction, and plastic products, the average annual turnover was almost $30.4 million USD, which is high.

Table 4.4

Characteristics of the Firms that Participated in Quantitative Research

Firm age (years)	Ratio (%)	Case(N)
≤5	3.9	5
≤10	10.5	13
≤15	26.3	33
≤20	40.8	52
>20	18.4	23
Average (yr)	16	
SD	7.1	
Min	3.0	

Employees	Ratio (%)	Case (N)
≤5	11.8	15
≤10	13.2	17
≤20	23.7	30
≤50	34.2	43
>50	17.1	22
Average	32.6	
SD	35.6	
Min	3.0	

[23] According to the meta-analysis of Rosenbusch et al. (2011), it takes 8–12 years for a company to mature depending on the industrial environment (Covin et al., 1990; Zahra, 1996). New venture businesses benefit more from innovation than mature SMEs.

Max	43.0

Max	210

Credit rating	Ratio (%)	Case (N)
≤CCC	13.3	17
B	25.3	32
BB	45.3	58
BBB	13.3	17
A	2.7	3
Average	-	
SD	-	
Min	-	
Max	-	

Annual average sales (million USD)	Ratio (%)	Case (N)
≤2	22.7	29
≤5	26.7	34
≤10	22.7	29
≤20	13.3	17
>20	14.7	19
Average	9.9	
SD	14.5	
Min	0.2	
Max	75.9	

4.3.2 Descriptive Statistics

Tables 4.5 and 4.6 show descriptive statistics of the variables used in the analysis. According to the Likert-scale measurement results, the mean values of the organization characteristic variables (e.g. R&D funding, marketing funding, identification of customer needs) are relatively lower than those of other characteristic variables. In particular, the level to which economic resources were secured was the lowest. This is a characteristic of SMEs, the target population in this thesis. In contrast, “technology superiority,” “top management commitment and visible support,” “competitive positioning,” and “relevance to environmental regulations” are relatively high. Competition in the target market was also perceived to be severe.

Table 4.5

Descriptive Statistics on Interval Scale Items

Variables	Cases (N)	Average	SD[a)]	SE[b)]
Product superiority	113	3.6948	0.8385	0.1112
Top management commitment and visible support	113	3.8608	0.7290	0.0968
Human resources dedicated to R&D	112[c)]	24.7744	19.2807	2.6211
Human resources dedicated to marketing	113	3.1667	0.8534	0.1134
R&D funding	113	2.7587	0.8703	0.1164
Marketing funding	113	2.7506	0.8712	0.1169
Market research skills	113	3.2013	0.8388	0.1116
Identification of customer needs	113	3.0930	0.8763	0.1165
Target market size	113	3.1564	0.9121	0.1220
Uncertainty (market/technology)	113	3.1831	0.9047	0.1208

Competitive intensity	112	3.4007	1.0053	0.1350
Competitive positioning	113	3.4394	0.7800	0.1034
Relevance to environmental regulations	113	3.8352	1.0382	0.1384
Level of environmental regulations	113	3.2122	1.0441	0.1397

a) SD: Standard Deviation, b) Standard Error, c) one unresponsive company

According to Table 4.6, 73.5% of respondents said that alternative or competitive technologies exist in the target market with regard to "first to market." Generally, environmental technologies (e.g. end-of-pipe technologies and eco-friendly processes) are characterized as alternative or improvement technologies in the market. Regarding "technology reliability," 81% of respondents said that the development technology's legality (i.e. field-scale test, operational performance, third-party verification) was not yet proven. Typically, the applied research stage government-funded R&D projects supported lab- or pilot-scale tests. Of the samples, 71.7% were in collaboration with external organizations (e.g. research universities and public-side research institutions) during the R&D phase. Of the respondents, 14.2% said that there was cooperation or customer participation in the R&D process and 12% said that they received financial support from the government after the end of government-funded R&D.

Table 4.6

Descriptive Statistics of Nominal-Scale Items

Variables	**Item**	**Frequency**	**Ratio (%)**
First to market	1	83	73.5
	2	30	26.5
Technological synergy	1	90	81.8
	2	20	18.2
Technology reliability	1	21	18.6
	2	92	81.4
Financial accessibility (multiple-choice questions)	1	76	58.0
	2/3	36	27.5
	4/5/6	19	14.5
Marketing proficiency	1	92	81.4
	2	21	18.6
R&D collaboration	1	81	71.7
	2	32	28.3
Cooperation with customers	1	16	14.2
	2	97	85.8
Government support policies	1	12	10.7
	2	100	89.3

4.3.3 Independent Sample T-test and Cross-tabulation Analysis

A small sample size relative to the number of independent variables can overestimate or underestimate the influence of independent variables in regression analysis.[24] This quantitative study has many explanatory variables compared to the sample size (i.e. 133 projects). To reduce the distortion of statistical results due to the small sample size, the author dropped statistically insignificant independent variables through "independent sample t-test" and "cross-analysis" prior to regression analysis. Eighteen explanatory variables were reselected as independent variables for binary regression analysis (see Table 4.7). There were four dropped variables: "first to market," "financial accessibility," "marketing proficiency," and "environmental regulation relevance." In particular, "first to market" may vary in importance depending on the researcher or context (e.g. the characteristics of industry and innovations) (Balachandra and Friar, 1997). In other words, the advantages of market preoccupation in the context of environmental technology did not affect the success of technology commercialization.

In the literature, regulatory pushes have been recognized as a key determinant of the diffusion of innovation. Nevertheless, "relevance to environmental regulations" was not statistically significant in the t-test results. The author can infer that a basic environmental regulatory system is already well-established in developed countries (e.g. OECD countries). In this regard, Korea already has a large market for major environmental sectors (e.g. air-quality management, water management, and waste management/recycling). Therefore, "relevance to environmental regulation," which is the initial market demand-generating factor, does not appear statistically significant. However, if environmental issues are highlighted as social issue it is different. For example, air pollution by PM (fine dust particles) constitutes both a serious environmental and social problem in South Korea; the government has announced additional related policies and related environmental regulations are continually tightened. In this context, further government regulation or stronger environmental regulations may be a catalyst for sales growth of "incremental environmental innovations." The results of quantitative research will be interpreted more abundantly in the convergence stage of this thesis.

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[24] According to Harrell (2001), when the sample size is m, the number of explanatory variables in a regression analysis should generally be $<m/10$.

Table 4.7

Results of Independent Sample T-test and Cross-tabulation Analysis

D.	Independent Variables	Scales of measure	T-test (p-value) (two-sided test)	Chi-square test (p-value) (two-sided test)	Independent Variable Selection
T	Product superiority	interval	0.000***		○
	Technology reliability	nominal		0.000***	○
	Technological synergy	nominal		0.000***	○
	First to market	nominal		0.294	
O	Financial accessibility	nominal		0.549	
		nominal		0.313	
		nominal		0.312	
	Top management commitment and visible support	interval	0.000***		○
	Human resources dedicated to R&D	ratio	0.024**		○
	Human resources dedicated to marketing	interval	0.044**		○
	Marketing proficiency	nominal		0.813	
	R&D funding	interval	0.000***		○
	Marketing funding	interval	0.000***		○
	Market research skills	interval	0.002***		○
	Identification of customer needs	interval	0.000***		○
	R&D collaboration	nominal	0.000***		○
	Cooperation with customers	nominal	0.000***		○
M	Target market size	interval	0.000***		○
	Uncertainty (market/technology)	interval	0.001***		○
	Competitive intensity	interval	0.051*		○
	Competitive positioning	interval	0.000***		○
E	Government support policies	nominal		0.005***	○
	Relevance to Environmental regulations	interval	0.205		
	Level of Environmental regulations	interval	0.070*		○

Note. Dimension: T (technology characteristics), O (organization characteristics), M (Market characteristics), E (environmental characteristics), * p<0.1, ** p<0.05, *** p<0.01

4.3.4 Correlation Analysis

If there is high correlation between independent variables, the multicollinearity problem may occur and the analysis result may be distorted. Therefore, the author confirmed the correlation between explanatory variables before analyzing the model. Table 4.8 shows the correlation analysis results for the variables with a correlation coefficient ≥0.6 ($p < .01$) among the independent variables.

Table 4.8

Correlation Analysis Result (Correlation Coefficient ≥ 0.6)

		1	2	3	4	5	7
1	Product superiority						
2	Top management commitment and visible support	**.623*****					
3	R&D funding	.379***	.280***				
4	Marketing funding	.347***	.312***	**.694*****			
5	Market research skills	.388***	.385***	.364***	.455***		
6	Identification of customer needs	.469***	.419***	.436***	.539***	**.751*****	

*** $p < 0.01$

The general method of solving multi-collinearity in statistics requires identifying the reason for correlation with the situation in the field collecting data and deleting or transforming one of the variables. Alternatively, the model can be used in spite of the multicollinearity (Gujarati & Porter, 2003). The author adjusted the variables with high correlation coefficients (six variables with a correlation coefficient of ≥0.6) based on the survey respondents' opinions and past new product performance literature. Eighteen independent variables were adjusted to 15; the following describes this variable adjustment.

According to survey respondents, several factors affect top management's decision-making in resource-scarce SMEs. For example, technology reliability, technology superiority, economic resources, target market size, and market potential can influence top management's decisions (e.g. project sustainability and fund investment decisions). In other words, “top management commitment and support” may be driven by the above independent variables, resulting in high correlation coefficients. Therefore, “top management commitment and visible support” is excluded from the quantitative study in this thesis. However, the literature review suggests that “top management's commitment and visible support” for innovation projects has been a key factor in the success of technology commercialization. Accordingly, the “top management commitment and support" factor is analyzed in-depth in the context of the environmental technology of SMEs in the qualitative study of this thesis.

In this study, based on the measurement items developed in the previous study, the author tried to measure the sub-concept as a single item. Therefore, financial resources are divided into "R&D funding" and "marketing funding." However, in the survey, respondents did not distinguish between R&D and marketing in their economic resources. Montoya-Weiss and Calantone (1994) proposed a "resources of money" factor that includes R&D and marketing funds. To solve the problem of the high correlation between independent variables, the authors merged two variables into "financial resources" and used the mean of the measured values. The "customer linkage" proposed by Datta *et al.* (2014) was used as "identification of customer needs" in this study (see Section 2.2.1.2.3). De Sousa Mendes and Devos Ganga (2013) measured "marketing skills" in terms of market research and identifying consumer needs.[25] To solve the problem of the correlation between independent variables, the author integrates "identification of customer needs" into the concept of "market research skills" (Ernst, 2002) and used the mean of the measured values.

After solving the correlation problem between the independent variables, the author conducted a correlation analysis of 15 independent variables (see Table 4.9). The correlation coefficients between the independent variables were all <0.6. Statistically, it was found that there is no mutual influence between independent variables. Statistically, the author found that there is no longer multicollinearity between independent variables.

[25] de Sousa Mendes & Devos Ganga (2013) measured "marketing skills" in three categories: 1.1 the market potential evaluation was well-conducted, 1.2 the consumers greatly desired this type of product, and 1.3 the user requirements were understood and translated for the product specifications.

Table 4.9

Correlation Analysis Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Technological synergy															
2 Technology reliability	.105														
3 Product superiority	.192**	.142													
4 Human resources dedicated to R&D	.047	.027	.212**												
5 Human resources dedicated to marketing	.219**	.105	.423***	.145											
6 Financial resources	.156	.235***	.394***	-.061	.367***										
7 Market research skills	.141	.046	.459***	-.004	.418***	.522***									
8 R&D collaboration	-.391***	-.255***	-.215**	-.150*	-.165*	-.072	-.035								
9 Cooperation with customers	.125	.255***	.169*	.191**	.045	.115	-.060	-.359***							
10 Target market size	.194**	.041	.265***	.064	.089	.212**	.187**	-.056	.086						
11 Uncertainty	.062	-.084	-.225***	-.139	-.184**	-.318***	-.216**	.031	-.184**	-.359***					
12 Competitive intensity	.089	.115	-.087	-.079	-.132	.002	.014	-.043	.186**	.217**	.020				
13 Competitive positioning	.269***	.252***	.547***	.055	.420***	.445***	.371***	-.237***	.142	.222**	-.253***	-.196**			
14 Government support policies	.111	.135	.161*	.080	.068	.268***	.203**	-.001	-.012	.203**	-.090	.065	.114		
15 Level of environmental regulations	.098	.001	.124	.057	.023	.046	.042	.009	.149*	.137	-.160*	.175**	.049	.088	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.3.5 Results of the Binary Logistic Regression Analysis

Table 4.10 shows the results of the binary logistic regression analysis. In the test of model coefficients, $X^2 = 83.767$, $p < 0.01$. This indicates that the independent variables are useful for analyzing environmental technology commercialization. The descriptive power is 72.6% (Nagelkerke $R^2 = 0.726$). According to the results of the Hosmer & Lemeshow fitness test, $p = 0.991 > .05$, so the model is suitable.

As a result of this analysis, two variables such as "technology reliability" ($p < 0.1$), "product superiority" ($p < 0.1$) in the technology characteristics dimension were found to have a statistically significant positive effect on technology commercialization. For "technology reliability," the odds ratio was 16.956, which is higher than that of other variables. This result demonstrates that the legitimacy of environmental technology such as field-scale tests, operational performance, and third-party verification play a key role in the environmental technology commercialization. When "product superiority" is increased by one unit, the odds ratio increases by 2.641. In other words, when the "product superiority" is increased by one unit, the probability of commercialization success increases 2.641 times.

Regarding variables related to organization characteristics, only "Market research skills" ($p < 0.1$) showed a statistically significant positive effect on commercialization. An increase of one unit in an enterprise's market research capacity increased the odds ratio by 2.981. In other words, if the market research skills increased by one unit, the success rate of commercialization would increase by 2.981 times.

The two variables "competitive intensity" ($p < 0.05$) and "competitive positioning" ($p < 0.05$) in the market characteristics were found to have a statistically significant positive effect on the success of technology commercialization. In the target market related to development technology, the odds ratio increased by 2.435 for each unit of competition intensity. If the competitive position in the target market was increased by one unit, the odds ratio increased by 3.889. The higher the "competition intensity" in the target market and the higher the "competition position" in the target market, the higher the probability of commercialization. In this study, "competitive intensity" was found to have a positive β value in contrast to existing theories in this field. In previous studies (e.g. Cooper, 1980; Yoon & Lilien, 1989; Maidique & Zirger, 1985), "strong competition" in the target market has been proposed as an obstacle to commercialization of new products.

The factors suggested as key determinants (e.g. government support policies and strong environmental regulations) in the previous study were found to have no statistically significant effect on the commercialization success of environmental technology.

Table 4.10

Results of Binary Logistic Regression Analysis

D.	Independent Variables	β	S.E.	Exp (β)
T	Technological synergy	1.614	1.213	5.021
	Technology reliability	**2.831***	**1.510**	**16.956**
	Product superiority	**0.971***	**0.542**	**2.641**
O	Human resources dedicated to R&D	0.012	0.025	1.013
	Human resource dedicated to marketing	-0.578	0.470	0.561
	Financial resources	-0.342	0.591	0.710
	Market research skills	**1.092***	**0.660**	**2.981**
	R&D Collaboration	-0.328	0.743	0.720
	Cooperation with customers	1.853	1.417	6.381
M	Target market size	0.380	0.428	1.463
	Uncertainty (market/technology)	-0.691	0.464	0.501
	Competitive intensity	**0.890****	**0.423**	**2.435**
	Competitive positioning	**1.358****	**0.612**	**3.889**
E	Government support policies	2.071	1.379	7.934
	Level of environmental standards	0.242	0.357	1.274
-		-14.242	4.537	.000
Number of Cases		113		
Chi-square ($\chi 2$)		83.767***		
Pseudo R^2 (Nagelkerke)		0.726		

Note. Dimension: T (Technology characteristics), O (Organization characteristics), M (Market characteristics), E (Environmental characteristics), * $p<0.1$, ** $p<0.05$

4.4 Discussion

The first research question in this thesis is: Which factors influence the commercialization of environmental technologies by SMEs?

According to the regression analysis, the five variables “technology reliability,” “product superiority,” “market research skills,” “competitive intensity,” and “competitive positioning” had a positive effect on SMEs’ commercialization of environmental technology. Of these five variables, strong technology reliability and technology superiority contributed greatly to the commercialization of environmental technology. Among the technology characteristics, technological synergy did not affect technology commercialization. Among the organization characteristics, human resources dedicated to R&D and marketing, financial resources, R&D collaboration, and cooperation with customers did not contribute to the commercialization of environmental technologies.

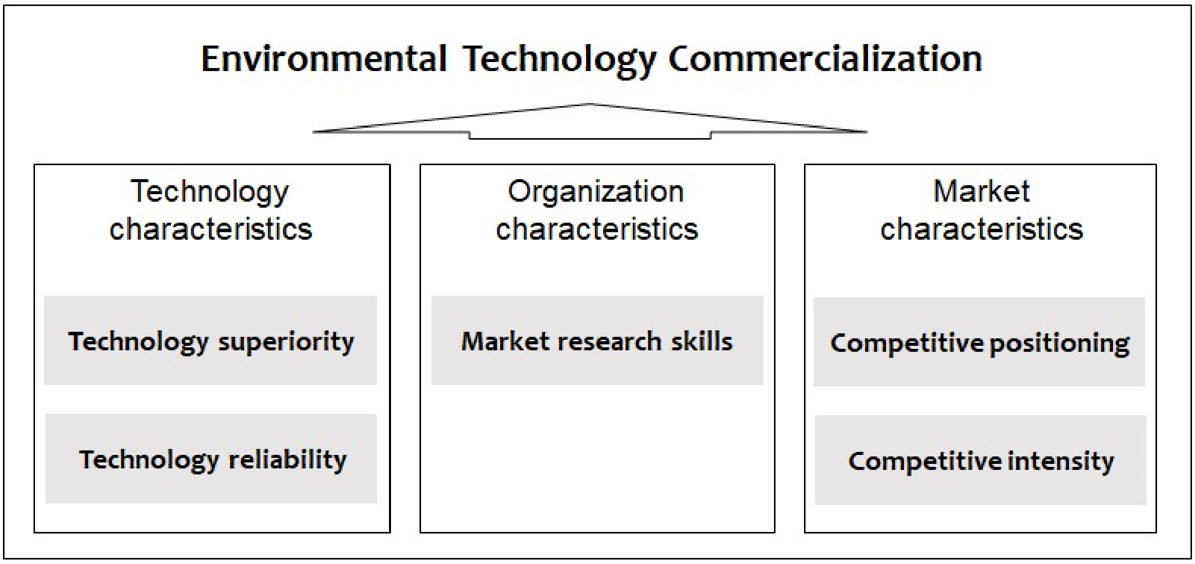
The market research skills variable had a positive effect on environmental technology commercialization. Companies that have commercialized environmental technologies have market research capabilities including market assessment, market research, research on market potential, research on market competition, and identification of customer needs. Among market and environment characteristics, target market size, market or technology uncertainty, government support policies, and strong environmental regulations did not influence commercialization of environmental technology. Only the competitive intensity and the competitive positioning in the target market had a positive effect on the commercialization.

According to the literature (Section 2.3), the key factors of technology commercialization are product superiority, technology reliability and market knowledge (or a company’s market research capabilities). In particular, in terms of environmental technology-related new product performance, the reliability factor of the technology including its legitimacy is an important factor for success. However, factors that could affect product superiority and technology reliability (e.g. technical synergy, top management commitment and support, customer linkage, government support policy (e.g. public R&D subsidies and infrastructure for startups), sufficient resources, collaboration with external organization in development) have not been identified as influencing factors in environmental technology commercialization. In particular, the results that the government's support policies (e.g. environmental protection policy and subsidy support) and environmental regulation (e.g. relevance and level of environmental regulations) factors were not identified as influencing factors in the process of commercializing environmental technology were unexpected. In the existing literature on environmental innovation diffusion (Rennings, 2000), regulatory push and policy pull factors have been recognized as key determinants. As already mentioned (Section 4.3.3), developed countries already have basic environmental regulatory systems in place. In this regard, Korea already has a large market for major environmental sectors (air-quality management, water management, and waste management/recycling). In particular, the target population of this quantitative study consists of >70% of the air, water, and waste sectors. In Korea, the air, water, and waste sectors account for >70% of the total environmental market. Considering the composition of the main target population in this quantitative study, environmental regulations and environmental support policies may be interpreted as less-important factors compared to other factors influencing the initial commercialization of environmental technologies.

In conclusion, for SMEs to commercialize environmental technologies, they should possess technology characteristics such as technological superiority and reliability. In addition, SMEs seeking to commercialize environmental technologies must have strong market research skills. Externally, the strong competitive position in the target market and high market introduction rate of the product category related to the development technology had a positive effect on commercialization (see Figure 4.5). In particular, the high rate at which new products are introduced in the relevant sector of the target market means that the product category is in the growth stage. This can be a good opportunity for new product development.

Figure 4.5

Factors Influencing the Commercialization of Environmental Technologies (Quantitative Research)



The second research question in this thesis is: How are the factors that influence the commercialization of environmental technologies by SMEs interrelated?

For SMEs to commercialize environmental technologies, they should take into account product superiority, technology reliability, and market research capabilities. Environmental technologies with incremental innovations already have many competitive technologies in the market. In other words, the successful market entry of environmental technologies basically requires "product superiority," which encompasses higher quality, higher price competitiveness, meeting customer needs, and allowing work that was previously impossible.

Regarding product characteristics, one important feature of environmental technology is technology reliability. SMEs that wish to commercialize environmental technologies should demonstrate to customers who want to introduce new environmental technologies that new environmental technologies always meet environmental regulatory standards. In particular, where new environmental technologies are applied to the post-treatment system of large production systems, it is necessary to demonstrate the system's stable operation.

Regarding a firm's market research capabilities, previous literature suggests that a firm's market-oriented activities—surveying customer needs, price sensitivity, market, potential, and the competitive environment— can help commercialize development technologies. In particular, in the case of environmental technologies, up-to-date information on environmental protection policies and new or enhanced environmental regulations can help new environmental technologies enter the market.

The commercialization of new environmental technologies requires that SMEs fulfill external factors such as the competitive advantage (competitive positioning) and intensity of competition in the target market. For a company to carry out new product development projects, it will have to continue investing resources after the development stage. Competitive advantages (competitive positioning) in targeted markets based on customer relationships for small- and medium-sized companies can increase the opportunities for market entry in the early commercialization of environmental technologies. In previous studies, "competitive intensity" has mainly been recognized as a barrier to commercialization (Cooper, 1979; 1980; Yoon & Lilien, 1989; Maidique and Zirger, 1985). However, some researchers (e.g. Balachandra, 1989; Islei *et al.*, 1991) found that a highly competitive environment means a high percentage of new product introductions to the target market and that the product category is in the growth stage. In other words, a certain competitive environment can present good opportunities for new product developments. On the SMEs side, even if there are many competitors in a target market rather than opening up a new market, the potential for commercialization can be increased if a market demand is abundant. However, the presence of strong competitors in a target market can negatively impact commercialization potential (Cooper, 1980).

CHAPTER 5: Qualitative Analysis

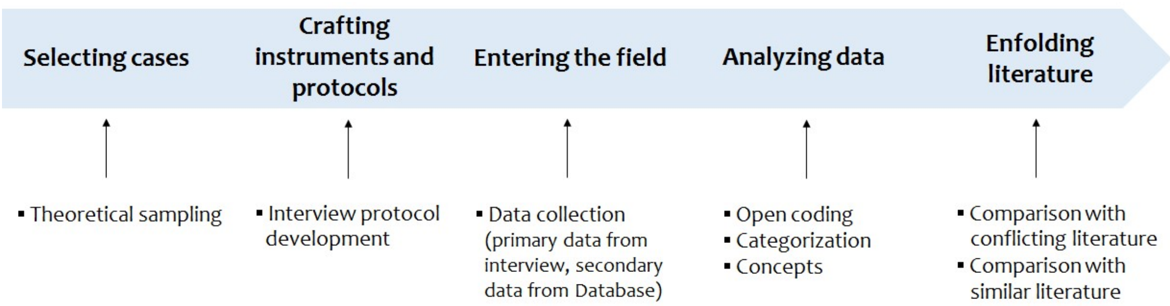
5.1 Methods and Procedure

This thesis applies a convergent parallel mixed-method design (Creswell & Clark, 2011, Tashakkori & Teddlie, 1998) that compares and contrasts quantitative research results from questionnaires with qualitative results from interviews and secondary data. The qualitative study in this thesis focuses on the main academic purpose of strengthening the theory test by methodological triangulation (Patton, 1990) in the empirical context of this study. Qualitative research can provide a correlation between factors, mechanisms and dynamics in the context of commercializing environmental technology in Korean SMEs.

The qualitative research method of this thesis is based on the phenomenological science philosophy and applies a multi-case study procedure (Yin, 2009). Qualitative data analysis methods use the constant comparative method proposed by Maykut and Morehouse (1994). Reasons for adopting the constant comparative method in qualitative research are powerful existing theoretical tests, mechanism identification, and the rich interpretation of results. The case selection method is applied to theoretical sampling (Glaser & Strauss, 1967) considering the research question and academic purpose of this thesis. For qualitative data, interview data and secondary data (i.e. a government Support R&D Program follow-up report) are used. For the target population of this thesis, 20 documents were collected at the R&D project level. Qualitative data analysis consists of three steps: open coding, categorization, and category identification. Figure 5.1 is a visual model for qualitative research in this thesis. The qualitative research procedure of this study follows the case study roadmap steps proposed by Eisenhardt (1989).

Figure 5.1

Visual Model of Multiple-case-study Qualitative Research



5.1.1 Case Selection

The author applied the theoretical sampling method considering the purpose of this thesis and the convergent parallel mixed-method design (Creswell & Clark, 2011; Tashakkori & Teddlie, 1998). Glaser & Strauss (1967) have long argued: "Cases are chosen for theoretical, not statistical, reasons." Eisenhardt (1989) stated that cases can be chosen to fill a theoretical category and provide extreme cases. Theoretical sampling refers to intentional sampling that purposefully selects concepts or objects that the researcher must explore based on the theoretical learning that the researcher has done prior to data collection (Glaser & Strauss, 1967; Strauss & Corbin, 1998). In theory, case addition ends at the theoretical saturation point (Morse, 2004:764). This sampling method provides an in-depth understanding of the research question (which factors influence the commercialization of environmental technologies by SMEs?) in this thesis. The author selected 20 of the 133 cases that participated in the quantitative research for qualitative research consisting of 10 success cases and 10 failure cases. Essentially, case choices were based on the willingness to participate in the research, the project performance, the business environment, and contents of various environmental technologies. Thereafter, interviews and initial coding were repeated for each case and 20 cases were finally selected (see Table 5.1). Douglas (1985) suggested that the ideal number of cases in a qualitative study aimed at theoretical exploration is around 25 cases. In terms of qualitative data analysis, 4–10 cases generally work well (Eisenhardt, 1989).

Table 5.1

Cases Selected for Case Study Analysis

Cases	Contents of Environmental Technology	Commercialization Contents	Firm age (years)	Interviewee Position
1	Hazardous gases treatment system	Partial technology of the system	13	Director
2	VOCs (volatile organic compounds) recovery/treatment system	Treatment system	22	R&D Manager
3	VOCs treatment system	Partial technology of the system	11	Managing Director
4	TOC measuring instrument (total organic carbon)	Measuring instrument	18	Managing Director

Cases	Contents of Environmental Technology	Commercialization Contents	Firm age (years)	Interviewee Position
5	Small- and medium-scale wastewater treatment system	Device of the system	19	Managing Director
6	Small-scale wastewater treatment system	Partial technology, small-scale ET system	3	Managing Director
7	Ozone generators with high energy efficiency	Device of the system	18	R&D Director
8	Eco-friendly product for medical-use	Product	14	Managing Director
9	Groundwater pollution treatment technology	Device of ET system	20	R&D Manager
10	Leachate and polluted groundwater treatment system	Treatment system	29	Principal Research Engineer
11	Exhaust gas filtration system	Treatment system	28	Managing director, R&D Manager
12	Industrial wastewater treatment technology	Treatment system	17	R&D Manager
13	Microdevice for heavy metal detection	Measuring instrument	12	Managing Director
14	Livestock wastewater treatment technology	Treatment system	8	R&D Manager
15	A sludge volume reduction technology	Pretreatment system	19	Managing Director
16	Metal wire recycling technology	Processing technology	12	R&D Manager
17	Waste energy(biodiesel) technology	Product (production technology)	19	Managing director, R&D Manager
18	Biogas production technology	Product (production technology)	16	R&D Manager
19	Electronic wastewater reusing technology	Processing technology (system)	20	Managing Director
20	Groundwater pollution treatment technology	Treatment system	18	Managing Director

Note. Cases 1~10: Success in Commercialization, Cases 11~20: Failure in Commercialization

5.1.2 Interview overview

The interview used an unstructured format, taking into account the constant comparative method (Maykut & Morehouse, 1994). The author prepared the conceptual framework for technology commercialization (Figure 2.2) but did not disclose this to the participants early in the interview. This was an effort to draw out participants' various experiential views. Before entering the field, the author explained the purpose of the interview to the participants and confirmed their intention to participate.

The interview was conducted in two stages. First, participants were asked to describe their position, technologies, and overall project. The purpose of this question was twofold, to get details of the case and to serve as an icebreaker (Hatch, 2002). Second, the author asked participants to explain the entire process from the early stages of their project to the success or failure of commercialization.

The interview took on average two hours. Due to the characteristics of SMEs, most of the research participants were able to fully express their experiences in the whole process from the planning stage of the technology to the commercialization process. If there were insufficient interviews, more detailed information could be obtained by providing a conceptual framework for technology commercialization.

5.1.3 Pilot Study

In qualitative research, a pilot study is used to collect empirical views of the participants related to factors in the technology commercialization process (see Figure 1.5). Through the pilot study, the adequacy of the interview method, the possibility of data collection, and the availability of results were examined. The pilot study involved one company that had commercialized development technology. One senior manager and one technical research director participated in the interview.

The company was a SME with >15 years of experience. As of December 2017, they have >50 employees, with an average annual turnover of >$10 million USD. The technology development was completed in 2014 and has generated economic performance of about $1 million USD annually thereafter. According to participants, the development goal of this technology is the localization of foreign technology. This technology has the advantages of technical excellence and price competitiveness.

The following quotation is related to the factors of technology commercialization.

"The strong will of the CEO and internal members (meaning employees) played

> a key role in driving the products and equipment with new technologies into the core business of the company." "Because there were already imported and competitor products in the market, we were able to secure the reliability of our products from potential customers by initially supplying them for free to enter the market."

The following extracts quotations related to technical commercialization barriers.

> "We are preparing public relations for local governments and facility operators but there is a lack of relevant information." "Promoting the product requires acquiring information on the operation status of the existing waste recycling facilities, information on the existing operating system (method) related to the product, and information on the customer's new business plan." "However, marketing capabilities are lacking."

At the start of the interview, requests for explanations of the technology development background and technology helped participants naturally concentrate on the interview. In addition, the fact that the author is the manager of the government-supported R&D programs has helped participants participate actively in interviews. In this case, the interview data was collected at a level that could be used as a citation for initial coding, although no additional information (conceptual framework for technology commercialization) was provided to participants. Since the company's senior manager and the director of the research institute participated in the interview, data from various perspectives could be collected. The author chose an unstructured interview method so that there was no need to modify or supplement the questionnaire.

The following implications were derived from the pilot interviews: (i) Interviews should be made for participants with extensive experience in technology development and commercialization projects; (ii) Participants with significant experience in technology development and commercialization projects provided a lot of information; (iii) It is important to understand each participant to facilitate the interview; for this, learning about the projects is an essential prerequisite of field visits.

5.2 Qualitative Data Collection and Analysis

5.2.1 Data Collection

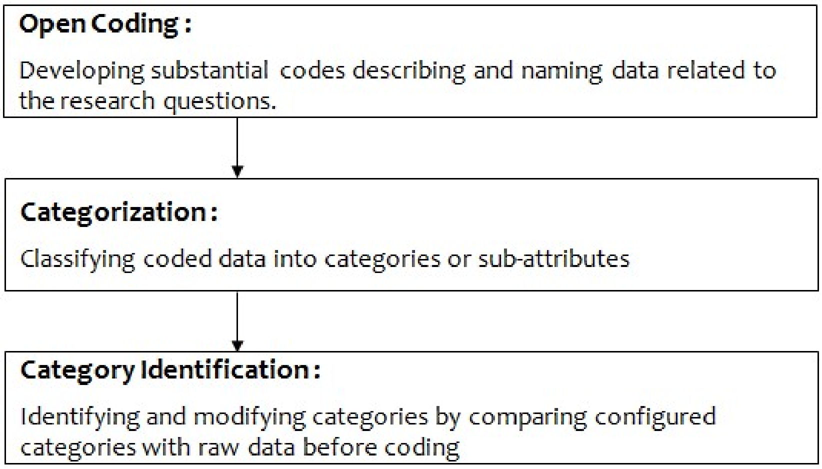
Qualitative data collection took place from June 2017 to April 2018. As the convergent parallel design was applied, qualitative data collection proceeded simultaneously with the quantitative phase. Questionnaires were not distributed in advance and participants were recruited by phone and email. Before entering the field, interview participants completed coordination with the company. Interviews were conducted with in-depth unstructured interviews through site visits and phone calls. The contents of the interviews were recorded by an electronic recorder with the participant's permission and the script was written immediately after each interview. Subsequent interviews—if necessary—were conducted over the phone. The author conducted sufficient pre-learning through the project's government-funded R&D report and official R&D management database for in-depth interviews. The author cross-checked interview data with secondary data and quantitative survey results to validate the information. Secondary data included government-funded R&D management databases and follow-up reports. Document data were collected from 20 cases as qualitative data.

5.2.2 Qualitative Analysis

According to the theoretical sampling method, qualitative data analysis was continuously conducted simultaneously with data collection (Merriam, 1998). Data analysis was performed by dividing into two groups (Group I; Success Cases, Group II; Failure Cases). The categorization results for failure cases complement the understanding of the factors that have a positive influence on environmental technology commercialization and the interrelationships between the factors. The constant comparison method according to Maykut and Morehouse (1994) was applied to the qualitative data analysis method. Documentation material (e.g. interview scripts) was used for the constant comparative method, and open coding and analysis was performed using ATLAS.ti version 8.0 qualitative analysis software. Figure 5.2 shows the procedure of the constant comparative method in this thesis' qualitative study.

Figure 5.2

Constant Comparative Data Analysis Method



Source: Reorganization of Maykut and Morehouse (1994)

5.2.2.1 Open Coding

Open coding is the task of naming and classifying important data while reading document data (Strauss & Corbin, 1990). The author repeatedly read the documents to familiarize himself with the 20 collected data documents. Through this, rough notes could be written at the beginning. Data segments with interesting content related to the research questions were coded. Open coding was done using Open coding and *in vivo* coding in ATLAS.ti v. 8.0, which is qualitative research software.

5.2.2.2 Categorization

After open coding, categorization was performed to classify coded data into the upper category. Categorization is an abstract conceptualization process that creates a complex concept that integrates multiple data through the process of iterative comparison and contrast (Merriam & Tisdell, 2015). The naming of the categories was mainly quoted from the theories presented in the previous research and the conceptual framework (see Figure 2.2) and concepts definitions (see Table 2.1) presented in this thesis. When naming a category, the author considered the following factors (Merriam and Tisdell, 2015): (i) The category names were inclusive of all sub-items; (ii) If some data belonged to more than one category, we copied the data and applied it to the appropriate category; (iii) The categories were named at a conceptually similar level.

5.2.2.3 Category identification

The open coding and categorization process has inductive characteristics but category identification is a deductive process (Merriam & Tisdell, 2015). The data analysis process ends when category identification confirms that a final category is well represented in relation to the research question (Ezzy, 2002). The process of reconfirming the original data was repeated to ensure that the categories constructed through the categorization process well described the characteristics of the data collected in relation to the research question.

5.3 Results

5.3.1 Results of Open Coding

Through initial coding, 97 codes were derived. Sixty-four codes were developed in Success cases (Case 1~10) and 33 codes in Failure cases (Case 11~20). Eighty paragraphs or sentences have been cited from 20 document data. The open coding derivation process is included in this thesis as Appendix 3.

5.3.2 Categorization Results (Group I)

Twelve categories and 26 subcategories were derived from the 64 codes. Each category's name is based on the conceptual framework (see Figure 2.2) and concepts definition (see Table 2.1) proposed in the literature review. Table 5.2 and 5.3 shows from which cases the variables are derived. The concept finally drawn up through categorization was classified into four dimensions according to the literature: technology characteristics, organization characteristics, market characteristics, and environment characteristics. The author adds the process from the open coding results to the category derivation in Appendices 3 and 4.

5.3.2.1 Technology Characteristics

▪ **Technology Superiority**

The "Technology superiority" concept incorporates the following subcategories: strong technological competitiveness, differentiation from competitive technology in the target market, ease of application, economic advantages for users, price competitiveness, technical performance, and technology completeness. In this study, “technology superiority” can also be expressed as technology competitiveness.

In particular, differentiation from competing technologies, economic advantages for users, ease of application, and technical performance are success factors that reflect the characteristics of environmental technologies. For example, a hazardous gas treatment system (Case 1), VOCs recovery, treatment system (Case 2), small- and medium-scale wastewater treatment system (Case 5), and small-scale wastewater treatment system (Case 6) are technologies that can sufficiently stimulate the necessity of introducing new environmental technologies to customers by solving the problems of existing technologies, very high treatment efficiency, and reducing operating costs. Specifically, Case 1 includes lower operating costs associated with heat recovery and higher removal efficiencies for hardly degradable VOCs. Case 2 includes high processing efficiency (including a shortened processing time) and operating cost reduction. Case 5 is a technology that solves the problems of existing technology and has high processing efficiency. In conclusion, technology superiority is the most fundamental and key factor for SMEs to commercialize environmental technology. The concept of technical superiority was derived from almost all successful projects (for example, technology superiority was derived from all cases except Case 10, which derives technology reliability) (see Table 5.3). “Technology superiority” of development technology is a core precondition that must be preceded first in a commercialization project. For example, top management commitment and investment (e.g. investment in subsequent R&D and mass production) in new projects stems from the “technical superiority” or technical competitiveness of a project technology (Cases 3 and 8). The success of commercialization in areas other than the environmental field as convergent technology was based on “technology superiority” and technology competitiveness (Case 2).

▪ **Technological Synergy**

The “Technological synergy” concept incorporates the following subcategories: improving technology and reliability based on the firm's expertise, applying to downstream processes, development of derived technology based on the firm's technology, development of excellent production processes based on the firm's technology, and possessing source technology.

According to the interview results, SMEs could expand the scope of their developed technology based on existing process operation expertise. In addition, additional commercialization was possible by applying development technology to the post-process of existing technology (Case 2). In Case 6, “technology superiority” (for example, developing a ceramic production method, which is a raw material for a membrane, with excellent characteristics and price competitiveness) was improved by creating links with a company’s existing technology. For SMEs that want to commercialize environmental technology, “technological synergy” is seen as a major factor in the success of commercialization. “Technological synergy” has been identified as a success factor in seven cases.

▪ **Technology Reliability**

“Technology reliability” incorporates two subcategories: demonstrating reliability through long-term operational performance and demonstrating reliability through field-test performance.

Companies wishing to commercialize an environmental technology system are required to demonstrate the reliability of their technology for the market. Proof of technology reliability (Corvellec and Bramryd (2012) described this as proof of legitimacy) refers to the confirmation of technical performance through long-term operational results and field tests. The demand for proof of “technology reliability” in the market also applies to component technologies and small devices. Since these components’ or small devices’ technologies are generally applied as part of a larger environmental technology system, the stable operation of the customer's existing system after applying a new product or new technology is an important technology selection requirement on the customer's side. For example, Case 10 was able to start a business based on pilot-scale operating performance. Case 5 started a business based on a proof-of-pilot operation during the commercialization of a small device. “Technology reliability” has been identified as an important success factor in six cases involving parts technologies, small devices, and ET systems (see Table 5.3).

▪ **Broad Application**

“Broad application” integrates three subcategories: wide range of applications, diversification of demand source, and application to other fields.

According to the interview results, “broad application” has two commercialization success dynamics in the context of SMEs’ environmental technology. In Cases 2 and 10, the companies succeeded in their initial commercialization in the target market segment, thus securing relevant process operation expertise. On this basis, companies are also entering other technology sectors, thus producing continuous sales. In other cases (Cases 4, 5, and 7), the companies are struggling with business in the target market segment, and succeeded in their initial commercialization by applying partial technology and small devices in other technology fields (e.g. livestock waste treatment or plating processes). In all relevant cases, technological competitiveness (i.e. excellent technical performance) was the foundation for the "broad application" to work. Companies gained confidence in technology from customers in other sectors by securing pilot-scale test results and operating results through initial commercialization (see Appendix 3).

5.3.2.2 Organization Characteristics

▪ Downstream Alliance Partnership

"Downstream alliance partnership" includes two subcategories: cooperation with external organizations across the value chain and sales outsourcing.

SMEs' environmental technology commercialization projects targeting large companies have high barriers to entry. According to the interview results, when SMEs commercialize environmental technology systems (including small- and medium-sized devices), customers (e.g. large corporations and public side institutions) want to adopt technology from suppliers with excellent process maintenance capabilities and risk-management capabilities (referring to the technical and economic capacity to follow-up in case of accidents after the application of technology). As a result, SMEs (Cases 3 and 6) that have successfully commercialized some of their products can generate initial sales through the formation of a commercial consortium with mid-size companies. Case 8 continues to generate revenue through sales outsourcing of medical products in the field of health-risk management. Companies focused on research and development can benefit from the success of commercialization through the use of relational resources (such as distribution or relationship mediation that are based on network relationships) when moving from R&D to commercialization (Aarikka-Stenroos & Sandberg, 2012).

▪ Market Research Skills

"Market research skills" includes two subcategories: well-planned R&D and identification of customer needs.

According to the interview results, Case 6 was based on the results of market research and competition technology research in R&D planning and technology development. The company has successfully commercialized parts technology development technology to solve the problems of existing small sewage treatment systems. The successful commercialization of parts technology has led to the successful commercialization of small-scale environmental technology systems. Case 10 collected information such as the budget and business plan for customers' related field during the government-funded R&D process. Based on this, field tests could be performed at the customer's workplace. The company succeeded in their initial commercialization based on the field test. In general, SMEs have difficulty finding places to perform field tests or pilot tests.

▪ **Good Technical Service**

"Good technical service" includes two subcategories: good technical service and customer training.

According to the interview results, Case 7 could gain trust in development technology and the company through after-sales service to customers after technology sales. For example, the company provided its customers with operational benefits (e.g. electricity savings, stability, and technical performance), optimal process proposals, and training related to process operations. The company was able to secure after-sales service capabilities based on the source technology. In other words, "technological synergy" can be attributed to "good technical service."

▪ **Top Management Commitment and Support**

"Top management commitment and support" is an important link for SMEs with limited economic resources to invest in subsequent R&D (e.g. field tests and third-party verification) and commercialization projects. Some Cases (Cases 3, 7, and 8) were able to invest in facilities for follow-up research and mass production with the active commitment from top management. According to the interview, Case 3 was able to make significant investments in the plant and production with the will of the top management although it was uncertain whether the developed technology would be commercially successful. Case 7 secured the reliability of the technology through follow-up research, which allowed it to start sales. While "top management's commitment and support" does not act as a direct success factor in the commercialization of development technology, it can affect technology superiority, high technology competitiveness, and high technology reliability.

5.3.2.3 Market Characteristics

▪ Competitive Intensity

According to the interview results, in the case of the VOC treatment system, market competition lowered the price of the regenerative thermal oxidizer (RTO) system (Case 1). The down price contributed to an increase in market demand for VOCs treatment. For example, a major customer of the VOCs treatment system was a large manufacturing facility. However, after the price was reduced, it could be expanded to production facilities of mid-size enterprises. Increasing market demand also contributed to users' economic advantages (e.g. heat recovery). The high intensity of competition in this qualitative study should be understood as the presence of multiple competitors in the target market. According to the literature, the presence of simple competitors in a market does not act as an obstacle to the success of commercialization (Cooper, 1980). In other words, the presence of many competitors in a target market lowers the market price of the environmental technology system, and the lower price acts as an increase in market demand. However, for the "competitive intensity" to be a success factor in the commercialization project process of development technology, technology superiority (or technical competitiveness) that can overcome market competition must be the basis.

▪ Competitive Positioning

According to the interviews, Case 9 is recognized as the best technology in groundwater decontamination from customers due to its competitive positioning in the target market. Based on its competitive advantage in the target market, the company has successfully commercialized it through its existing sales network. Operational performance was secured through the initial commercialization, and new customers are being found on this basis (see Appendix 3). The competitive positioning (e.g. company reputation, branding, and customer relationships) of a firm in the target market can contribute to the initial commercialization of SME environmental technologies.

5.3.2.4 Environment Characteristics

▪ Government Support Policies

In this study, “government support policies” includes the government's economic support policies for SMEs. Examples include low-interest loans and subsidies for R&D. Participants say the government's economic support policy targets technology suppliers and technology customers. According to Case 1, the government's economic support policy for environmental technology customers (e.g. low-interest loan support to adopt new environmental technology and various subsidies) has contributed to the growing market demand for development technologies. Cases 6 and 10 were able to pursue subsequent R&D projects through government-supported R&D. They were able to secure operational performance references through subsequent R&D aimed at field testing. This study reaffirmed the effect of the government's economic support policy as a factor in expanding market demand for environmental innovation. In addition, R&D funding policies aimed at technology suppliers helped demonstrate the technology’s reliability (or legitimacy).

▪ **Environmental Regulation**

“Environmental regulation” in this study includes three subcategories: high-level environmental standards, environmental regulator relevance, and environmental protection policy. Case 2 was successful in early commercialization supported by an environmental protection policy related to the recovery of VOCs in urban areas.[26] In addition, after entering the Hazards Air Pollutants (HAPs) treatment market, environmental regulations related to HAPs have been tightened. Strong environmental regulations have increased market demand, which has contributed to increased sales. As environmental regulations related to fine dust are tightened, the demand for hazardous gas abatement systems from mid-size companies is increasing (Case 1). Strong environmental regulations contribute to continued sales growth beyond the initial commercialization of new environmental technologies.

Table 5.2

Categorization Results (Group I)

	Categories	Sub-categories
1	Technology superiority	Strong technology competitiveness
2		Product advantage (differentiation over competitive offerings)
3		Product advantage (ease of innovation introduction and implementation)

[26] In South Korea, the Air Quality Preservation Act was amended in 2015. This law mandates the installation of a vapor recovery system for gas stations located in cities with a population of >500,000.

	Categories	Sub-categories
4		Product advantage (economic advantages of product for users)
5		Product advantage (lower-price product)
6		Product advantage (technical performance)
7		Completeness of technology
8	Broad applications	Broad applications in diverse market segments
9	Competitive positioning	Competitive positioning
10	Downstream alliance partnership	Cooperation with external organizations across the value chain
11		Sales outsourcing
12	Environmental Regulation	Environmental regulation relevance
13		High-level environmental standards (or new environmental-protection policies)
14	Government support	Government support (low-interest loans)
15		Government support (R&D subsidies (government support commercial-R&D))
18	Market research skills	Market research skills (well-planned R&D)
16		Identification of customer needs
17	Competitive intensity	Increased competition intensity
19	Good technical service	Provide a good technical service to customers (including customer training)
20	Technology reliability	Technology reliability
21	Technological synergy	Improving technology and reliability based on firm's expertise
22		Successful commercialization through linking existing business (applying to downstream process)
23		Development of derived technology based on the firm's technology
24		Development of excellent production processes based on the firm's technology
25		Possess original technology
26	Top management commitment/support	Top management commitment to innovation

Table 5.3

Factors by Case (Group I)

No.	Factors \ Cases	1	2	3	4	5	6	7	8	9	10
1	Technology superiority	○	○	○	○	○	○	○	○	○	
2	Technological synergy	○	○		○		○	○	○	○	
3	Technology reliability					○				○	○
4	Broad application		○		○	○		○			○

5	Downstream alliance partnership			○			○		○		
6	Market research skills						○				○
7	Good technical service							○			
8	Top management commitment/support			○				○	○		
9	Competitive intensity	○									
10	Competitive positioning									○	
11	Government support policies	○					○				○
12	Environmental regulation	○	○								

5.3.3 Categorization Results (Group II)

Ten categories and 14 subcategories were derived from the 33 codes of the failure cases. This category's name is based on the conceptual framework (see Figure 2.2) and concepts definition (see Table 2.1) proposed in the literature review. Table 5.4 and 5.5 shows from which cases the variables are derived. The concept finally drawn up through categorization was classified into four dimensions according to the literature as technology characteristics, organization characteristics, market characteristics, and environment characteristics. The author added the process from open coding results to the category derivation in Appendices 3 and 4.

5.3.3.1 Technology Characteristics

▪ **Technology Superiority**

In this study, "technology superiority" includes three subcategories: economic disadvantage of product to the user, low level of price competitiveness, and low technical performance. Projects that failed to commercialize were identified as low technical competitiveness in all but two cases (Cases 16 and 20). Participants pointed to the low technical completion of the project. The reasons for the low technical completion include failure to perform subsequent R&D or discovery of technical problems during subsequent R&D. In Case 11, a commercialization project was carried out on a partial technology of the developed environmental technology system but difficulty arose in commercialization due to the lack of price competitiveness. In addition, either the operating cost was high for users or the processing speed was slow compared to existing technology, which are barriers to commercialization (Cases 4 and 5). In conclusion, low technology competitiveness was identified as the most fundamental factor in the commercialization failure for SMEs' environmental technologies.

▪ **Technology Reliability**

"Technical reliability" includes two subcategories: absence of reference to operational performance and lack of technical performance verification.

This study is aimed at projects that have successfully completed lab-scale or pilot-scale tests through government-funded R&D. Nevertheless, low technology reliability was identified as a major failure in four cases. According to the interview results, cases in which low technical reliability was confirmed as a failure factor had techniques that failed the field-scale test. They could not drive the marketing itself because of low technology reliability. Customers who operate large facilities (e.g. large power plants and industrial wastewater treatment systems) want to introduce environmental technology systems with technical performance and stability through field-scale testing or proof of operational performance in actual processes (Cases 11 and 12).

5.3.3.2 Organization Characteristics

▪ **Downstream Alliance Partnership**

The "downstream alliance partnership" subcategory in this study is the failure to form a commercial consortium with mid-size companies.

According to the document data, Cases 11 and 12 are environmental technology systems applied to the post-treatment process of large facilities such as power plants or industrial wastewater treatment systems. As mentioned above, entry barriers are high when the customers of environmental technologies are large enterprises. Since large companies operate large production facilities, they do not want SME technology in terms of risk-management when introducing new technologies. Cases 11 and 12 failed to drive any business whatsoever due to the failure of consortiums with mid-size companies. Low technology reliability was the root cause of the failure to form a commercial consortium with mid-size companies.

▪ **Market Research Skills**

In this study, "market research skills" includes four subcategories: competition technologies research, identification of customer needs, policy trend research, and target market environment research. Four cases (Case 12, 13, 15, and 17) that were identified as lacking market research capability were found to be very poorly market researched during the technology development planning phase. For example, although a system was developed to recover expensive metals from industrial wastewater in Case 12, the market sells the wastewater without treatment. In addition, the biodiesel in Case 17 lacks the policy and institutional basis for commercialization as fuel. Two cases (Cases 12 and 17) had market conditions in which there was no market or marketing was impossible. According to the interview results, all four technologies are recognized as having low technological competitiveness (see Table 5.5, Appendix 3).

▪ **Financial Resources**

In "financial resources," the lack of economic and human resources has been identified as a subcategory. "Financial resources" were only identified as failure factors in Case 1. SMEs generally lack resources. Davidsson (2004) said that small- and medium-sized companies need innovative advantages to compete with large companies. In other words, a lack of resources was an obstacle for all companies involved in the study. The development technology in Case 11 is an exhaust gas treatment system for power plants or renewable energy. According to the interview, the technology requires that the supplier install a system in the customer's process. However, the high installation cost means that this is an obstacle to commercialization. The lack of resources in this study does not seem to work as an independent failure factor. Case 11 worked in combination with the following factors: low technology competitiveness, low technology reliability, failure of commercialization consortium, and lack of related commercial experience.

▪ **Marketing Proficiency**

The subcategory of "marketing proficiency" includes a lack of commercialization experience in the relevant sector. Lack of experience in commercialization was only confirmed in Case 11. Large companies require the submission of a successful market entry track record in the relevant field when introducing technology. Case 11 Companies are struggling with business because they have no commercial experience in air quality management. The technology developed in the Case 11 project is an exhaust gas filtration system.

▪ **Top Management Commitment and Support**

In the failure case, the "top management commitment and support" factor was only identified in Case 15. The interviews show that the top management in Case 5 had little willingness to accept the economic risks of subsequent R&D (e.g. field-scale tests and scaling-up) investments. In Case 15, the top management's low perception of new projects worked in combination with the following factors: low technology competitiveness and lack of market research at the R&D planning stage.

5.3.3.3 Market Characteristics

▪ **Uncertainty**

Case 18 was the only case in which "market uncertainty" in the commercialization phase was identified as a cause of failure. Case 18 was in the process of commercializing a project overseas after successfully completing government-funded R&D. However, the sudden drop in oil prices drastically reduced the added value of bioenergy. Economic difficulties meant that the commercialization of development technology was temporarily suspended. In Case 18, "low technology competitiveness" was also a major failure factor.

▪ **Availability of Raw Materials**

Cases 16 and 19 did not have a smooth supply of raw materials or components during the scale-up of development technologies. The results of the interview show that in Case 16, securing raw materials (waste) in the market as a waste recycling technology was difficult; meanwhile, Case 19 had no supply chain for the mass production of the core raw materials (see Appendix 3).

5.3.3.4 Environment Characteristics

▪ **Government Support (Policy Side)**

"Government support" includes the subcategory lack of government support (policy side). As a failure,"government policy support was only identified in Case 20. According to the results of the interview, groundwater purification technology is one area in which the government needs active policy intervention (see Appendix 3). In Korea, there is almost no market in the field of groundwater pollution purification except the government's temporary pilot project for groundwater purification. Activating the market would require economic incentives (subsidies for technology introduction and environmental taxes) and strict environmental regulations.

Table 5.4

Categorization Results (Group II)

	Categories	Sub-categories
1	Technology superiority	Economic disadvantages of the product to the user
2		Low level of price competitiveness
3		Low technical performance
4	Technology reliability	Low reliability of technology
5	Downstream alliance partnership	Failure to establish a downstream alliance
6	Market research skills	Lack of market research skills (competing technologies, customers, and demand)
7		Lack of market research skills (policy trends and market environment)
8		Product does not meet customer needs
9	Financial resources	Lack of financial resources
10	Marketing proficiency	No experience with similar project implementation
11	Top management commitment/support	Lack of risk acceptance by top management
12	Uncertainty	Uncertainty (market)
13	Availability of raw materials	Unavailability of raw materials
14	Government support (policy side)	Lack of government support (policy side)

Table 5.5

Factors by Case (Group II)

No.	Factors \ Cases	11	12	13	14	15	16	17	18	19	20
1	Technology superiority	○	○	○	○	○		○	○	○	
2	Technology reliability	○	○	○	○						
3	Downstream alliance partnership	○	○								
4	Market research skills		○	○		○	○	○		○	
5	Financial resources	○									
6	Top management commitment					○					
7	Marketing proficiency	○									
8	Availability of raw materials						○			○	
9	Uncertainty								○		
10	Government support										○

5.4 Discussion

The first research questions in this thesis are as follows: which factors influence the commercialization of environmental technologies by SMEs?

Through qualitative data analysis, the author derived 16 factors influencing SMEs' commercialization of environmental technologies (see Table 5.6). Six of them, “technology reliability,” “top management commitment and support,” “market research skills” (this includes “identification of customer needs”), “downstream alliance partnership,” and “government support” (policy side) were identified in both Group I and Group II.

Table 5.6

Factors Overview

D	No.	Factors	Group I (Success Cases)	Group II (Failure Cases)
T	1	Technological synergy	○	
	2	Technology reliability	○	○
	3	Technology superiority	○	○
	4	Broad application	○	
O	5	Top management commitment/support	○	○
	6	Marketing proficiency		○
	7	Financial resources		○
	8	Market research skills	○	○
	9	Downstream alliance partnership	○	○
	10	Good technical service	○	
M	11	Uncertainty (market)		○
	12	Competitive intensity	○	
	13	Competitive positioning	○	
	14	Availability of raw materials		○
E	15	Environmental regulation	○	
	16	Government support policies	○	○

Note. Dimension: T (technology characteristics), O (organization characteristics), M (Market characteristics), E (Environment characteristics)

The results of categorization for failure cases in qualitative research complement the understanding of the factors that have a positive influence on environmental technology commercialization and the interrelationship among the factors.

▪ **Technology Characteristics**

“Technology superiority” encompasses differentiation from competing technologies, ease of applications, economic advantages for users, price advantages, strong technical performance, and technology completeness. Specifically, factors such as solving the problems of existing technologies (enabling previously impossible things), very high pollutant treatment efficiency, and reducing operating costs through heat recovery can greatly increase the commercialization potential of environmental technologies.

“Technology reliability” refers to the stable operation of new environmental technology systems. “Technology reliability” can be proved through pilot-scale or long-term operation results and third-party verification.

“Technological synergy” refers to the improvement of environmental new product development’s technological superiority (e.g., obtaining excellent production technology, quality improvement) by building on a company's process operation expertise, technical expertise, and source technology.

“Broad application” includes various application, diversification of demand. It can be defined as “how the application of innovation can be diversified.” (in line with Brown *et al.,* 1991)

▪ **Organization Characteristics**

“Top management commitment and support” determines the input of resources (human and financial resources) needed in subsequent R&D (this includes quality improvement, field tests, and technology verification), mass production, and marketing processes in an SME environment that lacks economic capacity. “Top management commitment” includes acceptance of economic risks.

A company’s strong “market research skills” include identification of customer needs and well-planed R&D.

“Downstream alliance partnership” includes cooperation with external organizations across the value chain (e.g. establishing a commercial consortium with mid- or large-sized enterprises) and sales outsourcing.

“Good technical service” refers to a good technical service to customers (including customer training).

▪ **Market Characteristics**

"Competitive intensity" refers to the presence of many competitors in target markets. The presence of many competitors in existing markets can drive down the market price of technology, which can lead to increased market demand. For example, a drop in the price of an ET system can extend technology customers from large enterprises to mid, small businesses.

"Competitive positioning" refers to customer confidence based on corporate competitiveness in the target market.

▪ **Environment Characteristics**

"Government support policies" refers to a support policy targeting technology suppliers and market customers. Government support policies for technology suppliers (corporate) include commercial-R&D subsidies and low-interest loans. Support policy targeting market customers means subsidies and low-interest loans paid to customers of new environmental technologies.

"Environmental regulation" includes stricter environmental regulation and new environmental protection policies (e.g., GHG reduction policy, PM reduction policy, VOCs reduction policy in urban areas, etc.).

The second research question in this thesis is: How are the factors that influence the commercialization of environmental technologies by SMEs interrelated?

Here, the author presents the interrelationships and dynamics of factors in the process of commercializing environmental technologies based on qualitative findings, literature reviews (Chapter 2), and the author's knowledge (The author is the manager of a government-supported R&D program in Korea).

▪ **Technology Characteristics**

Environmental technologies involved in incremental innovation already have many competitive technologies in the market. Accordingly, the following factors can be attractive to customers who are considering purchasing new environmental technologies: Strong technical competitiveness, differentiation from existing technology, problem-solving for existing technology (enabling previously impossible work). For example, in qualitative research (Cases

1, 2, 5, and 6), factors such as problem solving of existing technologies, very strong processing efficiency, and reduced operating costs all worked as strong technology push factors.

Since the environmental technology system is applied to the back-end of a large production process, it is very difficult for customers to select a technology if its completeness and reliability are unproven. For example, in an exhaust gas filtration system applied to a thermal power plant, if a problem occurs in the ET system during power generation, all processes must be shutdown, which can have a major economic impact. “Technology superiority” and “technology reliability” in new product development projects are the most fundamental and key factors for technology commercialization success (in line with Balachandra and Friar, 1997). They can affect all stages of R&D, mass production, sales, etc. after the development stage in the process of new product development. According to the results of the analysis of failure cases, low technology competitiveness was identified as the most fundamental factor in the commercialization failure for SMEs environmental technologies (see Section 5.3.3.1). The factors of “technology superiority”, “technology reliability”, and “top management commitment and support” closely affect each other. The top management should presuppose the superiority of development technology to invest in subsequent R&D, and this investment has a positive effect on technology reliability. “Technology reliability” again affects top management's investment decisions in mass production and marketing.

Companies can improve the “product superiority” and “technology reliability” of new environmental technologies through building on process operation expertise and source technologies and thus enter the market faster than their competitors. In addition, it is relatively easy to succeed in the initial commercialization by connecting new environmental technologies to the bottom of the company's existing system. Companies can provide “good technical service” such as optimal process proposal, operation effect verification, and after-sales service training program to consumers based on process operation expertise, technical expertise and source technology. In this process, “good technical service” contributes to the improvement of “technology reliability” and “competitive positioning” in the company's target market.

In addition, based on the process operation expertise and “technology superiority”, a company can extend its scope to other areas beyond the target market (this is expressed as “broad application” in qualitative findings). The technology commercialization process is very complex and can be influenced by a combination of factors (Datta *et al.*, 2014), which allows a company to flexibly respond to changes in the market environment (e.g. changes in government environmental policies and changes in social environmental issues) during the commercialization process through a “broad application.” The acquisition of new customers based on the “broad application” enables the continuous expansion of sales of new environmental technologies.

▪ **Organization Characteristics**

Market knowledge-including customer needs, price sensitivity, market potential, competitive environmental information, environmental regulations, and policy information-requires constant updates in the overall new product development process. Market knowledge can positively impact “technology superiority” through well-planned R&D of new product development projects. Well-planned R&D, which includes a competitive environment survey, helps to differentiate from existing technologies, solve problems in existing technologies, and allow previously impossible tasks (these are subcategories of "technology superiority"). Market knowledge can help in obtaining sites for field testing in the post-development process and finding customers.

“Top management commitment and support” determines the input of resources—human and financial resources— needed in subsequent R&D (this includes quality improvement, field tests, and technology verification), mass production, and marketing processes in an SME environment that lacks economic capacity. Large-scale environmental technology systems (such as waste-to-energy and material recycling systems and waste-to-energy systems) require a large initial investment in technical education and system installation for customers during commercialization. In particular, the acceptance of economic risks by top management can support many initial investments. The establishment of a commercial consortium with large- or mid-size companies (meaning downstream alliance partnerships) can complement customer relationships and economic risk acceptance in the commercialization process. In particular, for SMEs to commercialize an environmental technology system applied to large-scale production facilities (e.g. power plants, steel mills, and sewage treatment plants) may require forming a commercialization consortium with large or mid-sized companies. Through a consortium, SMEs can complement the acceptance of economic risks.

▪ **Market Characteristics**

Qualitative studies show that in the case of VOCs treatment systems, competition in the market lowers the price of the regenerative thermal oxidizer (RTO) system, which in turn leads to increased market demand. More specifically, due to the lower price of the RTO system, the demand for new environmental technology has expanded from large and medium-sized companies to small and medium-sized enterprises. The lower price of environmental technology can meet both regulatory and technology push on the customer side. The reason lower prices are linked to increased market demand can be interpreted as lower prices affecting regulation push and technology push. Customers can meet environmental regulations and reduce operating costs at relatively low prices (Case 3 is a technology that can differentiate from the existing technology, have easy implementation, and give the user an economic advantage). Of course, new environmental technologies should have "technology superiority" and "technology reliability."

The "competitive positioning" of a company in its target market is based on the customer relationship of the existing business, making it easier to achieve early commercialization than the competition. A company's technology that has competitive positioning in the target market, is perceived by the customer as a superior technology.

▪ **Environment Characteristics**

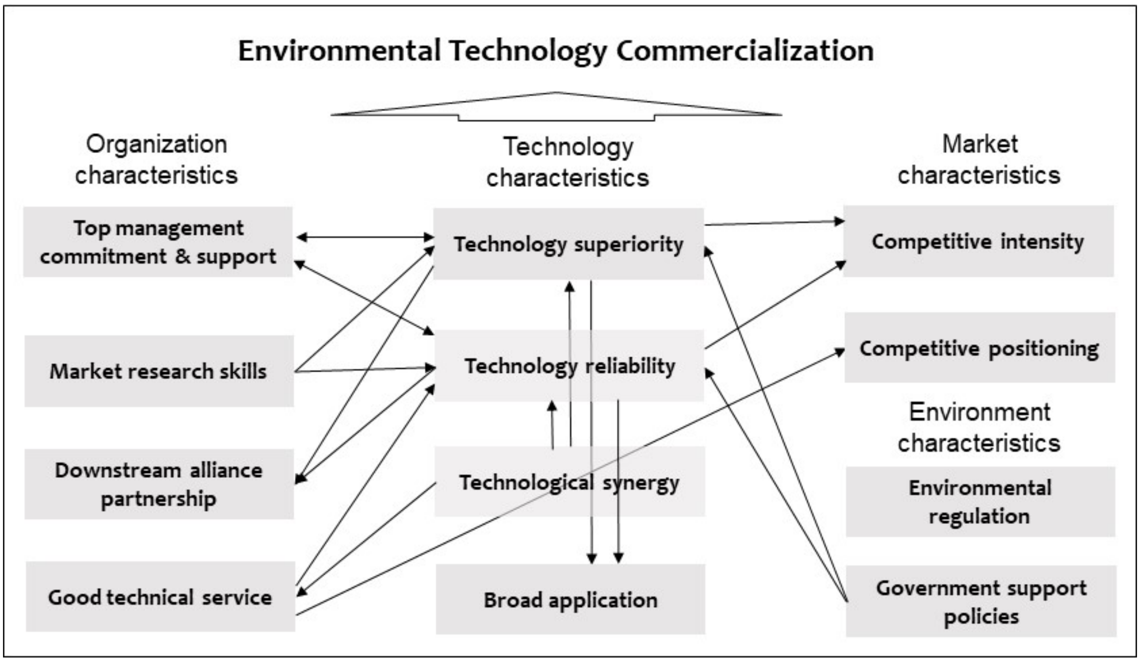
For resource-poor SMEs, "government support policies" such as public R&D subsidies, low-interest loans, infrastructure of startups, etc. can contribute to improved "technology superiority" and "technology reliability" through subsequent R&D, field tests, and technology verification support.

New environmental protection policies, such as reducing PM and VOCs in urban areas, can create new environmental market demands. Based on environmental protection policies, companies can generate initial sales of new environmental technologies relatively easily. Stricter environmental regulations for air and water pollutant-generating facilities could be the basis for continued sales growth of environmental technologies. This is the result of explaining regulatory push among the determinants of the diffusion of environmental innovation. Analysis of the success group (see Appendix 3, 4) indicated that there are only two cases where "environmental regulation" was found to be a success factor (Cases 1 and 2). Cases 1 and 2 are successful in commercialization or generate continuous sales due to the government's strict fine dust regulations and urban VOCs reduction policies. In other cases, "environmental regulation" was not mentioned as a success factor. As already mentioned (Figure 1.4), the air, water and waste sectors account for more than 70% of the total sales in the environmental market in Korea, and the environmental regulation system is well established. At least in these environmental sectors, environmental regulations seem to contribute little to the initial commercialization success. Accordingly, it can be interpreted that the technology push factors, rather than environmental regulations, have driven the market demand. Technology push factors include technical customer incentives such as energy efficiency, product quality (high pollutant treatment efficiency) and material efficiency. In conclusion, if there is already an environmental market and a well-established environmental regulation system, at least the success of initial commercialization may be driven by the technology push factor. In terms of environmental technology commercialization, the factor of technology push can be related to technological superiority and technical reliability. “Technology superiority” includes factors such as solving the problems of existing technologies (enabling previously impossible things), very-high pollutant-treatment efficiency, and reducing operating costs (economic advantage to the customer) through heat recovery. “Technology reliability” proves to customers the stable operation and legitimacy of new environmental technologies.

Figure 5.3 Illustrates the factors and mechanisms of the successful commercialization of environmental technologies based on qualitative findings.

Figure 5.3

Factors Influencing of and Mechanisms of the Commercialization of Environmental Technologies (Qualitative Research)



CHAPTER 6: Merging and Convergence

6.1 Merging

In the merging phase of the convergent parallel mixed-method design, the quantitative and qualitative findings are compared and contrasted to complement each other (Creswell & Clark, 2011). The merging and convergence process of research results conducted in parallel allows a deep understanding of the validity of the research results and the reality (Brewer & Hunter, 1989). The factors found in each study were classified into four characteristics and displayed according to the side-by-side comparison method (Creswell & Clark, 2011). The author referred to the summary table format of Li *et al.* (2000) as a display method (Creswell and Clark, 2011, p225).

6.1.1 Merging of the Two Sets of Results

The merging results show the factors influencing the commercialization of environmental technology found through quantitative and qualitative studies through simultaneous display. In table 6.1, the mechanisms and subcategories identified through qualitative studies are displayed together. Subcategories help to understand factors. This provides detailed information on the factors influencing and mechanisms of environmental technology commercialization.

Table 6.1

Display of Quantitative and Qualitative Findings through Side-by-side Comparison

D	Quantitative study result	Qualitative study result	
	Influencing factor	**Influencing factor**	**Mechanism and subcategories**
T	Technology superiority	Technology superiority	- Acts as a prerequisite for "downstream alliance partnership," "broad application," and "competitive intensity" - Complementary relationship with "top management commitment and support" - Subcategories: differentiation over competitive offerings, ease to introduction and implementation, economic advantage of product to the users, lower priced product, technology performance.

D	Quantitative study result	Qualitative study result	
	Influencing factor	Influencing factor	Mechanism and subcategories
	Technology reliability	Technology reliability	- Acts as a prerequisite for "downstream alliance partnership" and "competitive intensity" - Complementary relationship with "top management commitment and support" - Acts as a prerequisite for sales of development technology - Subcategories: proof of reliability through long-term operation, proof of reliability through performance of field scale test
	-	Technological synergy	- Support "technology superiority," "technology reliability," and "good technical service" - Subcategories: utilization of technical expertise, applied to downstream process, derived technology development, gain superior production technology, utilization of source technology
	-	Broad application	- Support expansion of business - Subcategories: wide range of applications, diversification of demand source, application to other fields
O	Market research skills	Market research skills	- Support "technology superiority," "technology reliability," and "downstream alliance partnership" - Subcategories: well-planned R&D, identification of customer needs, identification of target market demand, obtaining customer information such as budget, business plan .
	-	Downstream alliance partnership	- Subcategories: cooperating with external organization (e.g. medium sized firm) across the value chain, sales outsourcing
	-	Good technical service	- Support "technology reliability," "competitive positioning" - Subcategories: after-sales service, optimal process proposal, after-sales service education program
	-	Top management commitment and support	- Support "technology superiority," "technology reliability," and "market research skills" - Subcategories: determination of investment for subsequent R&D and mass production
M	Competitive intensity	Competitive intensity	- Support the expansion of market demand (subcategory not identified)
	Competitive	Competitive	- Induce customer confidence

D	Quantitative study result	Qualitative study result	
	Influencing factor	Influencing factor	Mechanism and subcategories
	positioning	positioning	- Subcategory: customer's trust
E	-	Environmental regulation	- Support new market creation, -to expand market potential - Subcategories: enhanced or new environmental regulation, environmental regulation relevance, environment protection policy
	-	Government support policies	- Support "technology superiority," "technology reliability" - Subcategories: supporting low-interest loan, subsidy for R&D (government support commercial-R&D), various subsidy systems

Note. Dimensions: T (technology characteristics), O (organization characteristics), M (Market characteristics), E (Environment characteristics)

According to the merging results, a total of 12 factors were identified. Five factors ("technology superiority," "technology reliability," "market research skills," "competitive intensity," and "competitive positioning") found in quantitative research were also found in qualitative research. The qualitative findings add the following factors: "technological synergy," "broad application," "downstream alliance partnership," "good technical service," "top management commitment and support," "environmental regulation," and "government support policy."

According to factors influencing of and mechanisms of the commercialization of environmental technologies (Figure 5.3) and merging results (Table 6.1), four factors not found in quantitative studies—"technological synergy," "top management commitment and support," "good technical service," and "government support policy"— contribute to the commercialization by supporting other factors. According to merging results, "technological synergy" supports "technology superiority," "technology reliability" and is the basis for "good technical service." Companies can improve "technology superiority" and "technology reliability" of new environmental technologies through building on process operation expertise and source technologies, and thereby enter the market faster than competitors by reducing the development time. "Top management commitment and support" is complementary to "technology superiority" and "technology reliability." In particular, it supports "technology superiority," "technology reliability," "market research skills" through investment decisions such as subsequent R&D, field tests, technology verification, and market research in the environment of SMEs with insufficient economic capacity. "Government support policy" refers to the government support policy for small and medium-sized companies—commercial-R&D subsidies, low-interest loan, infrastructure of startups—, which contributes to the improvement of "technology superiority" and "technology reliability" through subsequent R&D, field test and technical verification support. Companies can provide "good technical service" such as optimal process proposal, operation effect verification, and after-sales service training program to consumers based on process operation expertise, technical expertise and source technology. In this process, "good technical service" contributes to the improvement of "technology reliability" and "competitive positioning" in the company's target market.

"Broad application" should be basically supported by "technology superiority." New environmental technologies with a "broad application" can flexibly respond to changing market conditions. More specifically, if it is difficult to enter the target market, market entry can be successful by changing the target market to another field. After successful commercialization, the company can expand into other fields based on its operating results and expect to continue to expand sales. "Broad application" has not been identified in the conceptual framework (Figure 2.2) presented by the author.[27] The concept of technology coverage was defined as the breadth of possible application in the literature on technology transfer strategies (Brown *et al.*, 1991). According to Brown *et al.* (1991), "breadth of possible applications" is defined as "how the application of innovation can be diversified."

The establishment of a commercial consortium with large- or mid-size companies (meaning downstream alliance partnerships) can complement customer relationships and economic risk acceptance in the commercialization process. In particular, for SMEs to commercialize an environmental technology system applied to large-scale production facilities (e.g. power plants, steel mills, and sewage treatment plants) may require forming a commercialization consortium with large or mid-sized companies. Through a consortium, SMEs can complement the acceptance of economic risks. According to the results of previous eco-innovation studies and qualitative study in this thesis (Cases 1 and 2), new environmental protection policies and strict environmental regulations contribute to the creation of markets or

[27] In the literature review strategy of this thesis, the author excluded empirical studies of non-profit organizations that do not directly carry out the technology commercialization process.

to the expansion of market demand. Nevertheless, the factors related to "environmental regulation" in the statistical and quantitative studies of this thesis were not identified as key factors. Interpretation of the contrast and comparison results of quantitative and qualitative results is described in Section 6.2.

6.2 Convergence

In the final stage of the comprehensive research method of this thesis, the convergence stage, based on literature reviews, quantitative and qualitative findings, identifies the factors influencing and mechanisms in the process of commercializing new environmental technologies.

The author identified twelve factors through merging (section 6.1) results. Five ~~success~~ factors ("technology superiority," "technology reliability," "market research skills," "competitive intensity," and "competitive positioning") found in quantitative research were verified in qualitative research. The qualitative study finds seven additional factors, complementing the quantitative findings: "technological synergy," "broad application," "downstream alliance partnership," "good technical service," "top management commitment and support," "environmental regulation," and "government support policy."

6.2.1 Technology Characteristics

The most fundamental and key factors influencing commercialization of environmental technology are the technology characteristics "technology superiority" and "technology reliability." SMEs need to have an innovative edge in order to compete with large companies and succeed (Schumpeter, 1982; Davidsson, 2004). Quantitative research shows that high technology superiority and technology reliability statistically significantly increase the probability of commercialization of environmental technology 2.6-fold and 16.9-fold. "Technology superiority" encompasses differentiation from competing technologies, ease of application, economic advantages for users, price advantages, technical performance, and technology completeness. In particular, the following factors can be attractive to customers considering the introduction of new environmental technologies: strong technical competitiveness, differentiation from existing technology, and problem solving of existing technology (enabling previously impossible work). "Technology reliability" includes the stable operation and legitimacy of new environmental technology systems. Since the environmental technology system is applied to the back-end of a large production process, customers basically want to purchase a technology that has proven completeness and technology reliability. Legitimacy means consistently meeting environmental regulations. “Technology superiority” and “technology reliability” in new product development projects are the most fundamental and key factors for technology commercialization success (in line with Balachandra and Friar, 1997), which can affect all stages of the R&D, mass production, sales, etc. after the development stage in the process of new product development. In particular, low technology completeness and reliability can have a negative effect on the process of commercializing environmental technologies.

“Technological synergy,” “top management commitment and support,” “market research skills” and “government support policies” have a positive effect on “technology superiority” and “technology reliability.” By building on existing technologies, companies can contribute to “technology superiority,” such as superior characteristics of development technology and price competitiveness. Top management commitment is the key link to investment decisions for subsequent R&D and marketing practices. In particular, subsequent R&D investments can affect “technology superiority” and “reliability.”

Market knowledge based on a firm's market research capabilities (e.g., market research, competitive technology research, etc.) can help differentiate it from competing technology and meet customer needs through well-planned R&D. Firms can expand the scope of technology based on their “technology superiority.” New environmental technologies with a “broad application” can flexibly respond to changing market conditions. More specifically, if it is difficult to enter the target market, the market entry can be successful by changing the target market to another field. After successful commercialization, the company can expand into other fields based on its operating results and expect to continue expanding sales.

6.2.2 Organization Characteristics

The quantitative research in chapter 4 showed that a firm with strong “market research skills” can increase the probability of commercializing environmental technology 2.9-fold. Successful projects on new product development should integrate technical research with market research (Cooper, 1980). Ernst (2002) emphasized continuous information updates through market research throughout the process of new product development. Companies can increase “technology superiority” and “technology reliability” through “market research skills”. The qualitative research in Chapter 5 showed that a firm's strong “market research skills” enables it to identify problems with existing technologies in the target market and to develop alternatives that better meet customer needs. Identifying problems with existing technologies can be the basis for “technology superiority” (e.g. differentiation from existing technology, problem solving of existing technology, allowing previously impossible work). Information related to the business plan of the customer can help in obtaining sites for field testing in the post-development process and finding customers. Well-planned R&D and identification of customer needs based on market knowledge can significantly reduce the risk of failure in the commercialization process after technology development.

“Top management commitment and support” is a factor that has a positive influence on commercialization of environmental technology that has been supplemented through qualitative research. According to previous innovation literature, top management commitment and visible support are critical for companies to overcome barriers and resistance to innovation (Rothwell, 1992). According to the qualitative studies in Chapter 5, “top management commitment and support” determines the input of resources (human resources, funds) needed in subsequent R&D (it includes quality improvement, field test, technology verification, etc.), mass production, and marketing processes in an SME. Large-scale environmental technology systems (waste-to-energy and material recycling system, waste-to-energy system, etc.) require a large initial investment in technical education and system installation for customers during commercialization (Gonzalez, 2009). In particular, top management's risk-acceptance of initial investment should be supported. In addition, “top management commitment and support” is influenced by “technology superiority” and “technology reliability.” The top management should presuppose the “technology superiority” of development technology to invest in subsequent R&D, and this investment has a positive effect on “technology reliability.” “Technology reliability” again affects top management's investment decisions in mass production and marketing.

“Downstream alliance partnership” is a factor that has a positive influence on commercialization of environmental technology that has been supplemented through qualitative research. According to the existing research on new product performance, innovation companies need relational resources when moving from an R&D task to a commercialization task. For innovators, relational resources (e.g., commercialization capabilities such as distribution, marketing communications, relationship mediation, etc., based on network) helped the commercialization of innovating companies. Qualitative research shows that the establishment of a commercial consortium with large or medium-sized companies (referred to as a downstream alliance partnership in qualitative research) can complement the acceptance of economic risks and customer relationships in the process of commercialization. In connection with the introduction of environmental technology systems that apply to large production facilities—power plants, steel mills, sewage treatment plants—, customers ask small businesses to form consortiums with large or medium-sized businesses. Customers can prepare for unexpected accidents (e.g. breakdown of a post-treatment process which requires maintenance by a technology supplier) by dealing with large or medium-sized companies. “Technology superiority” and “technology reliability” of new environmental technologies are a prerequisite for the construction of a consortium.

Companies can provide “good technical service” such as optimal process proposal, operation effect verification, and after-sales service training program to consumers based on process operation expertise, technical expertise and source technology. In this process, “good technical service” contributes to the improvement of “technology reliability” and “competitive positioning” in the company's target market.

6.2.3 Market Characteristics

The quantitative research in Chapter 4 shows that competition intensity in target markets can increase the probability of commercializing environmental technologies 2.4-fold. The high rate of introduction of new products in the relevant sector in the target market means that the product category is in the growth stage. This can be a good opportunity for new product success (Balachandra, 1989; Islei *et al.*, 1991). The presence of simple competitors in the market does not act as an obstacle to commercialization (Cooper, 1980). Qualitative research of this thesis shows that the presence of many competitors in the target market causes the price of environmental technology systems to fall, leading to increased market demand. For example, in the case of VOCs (volatile organic compounds) treatment systems, competition in the market lowers the price of the RTO (regenerative thermal oxidizer) system, which in turn increases market demand. Specifically, the demand for new environmental technology has expanded from large and medium-sized companies to small and medium-sized enterprises. The interpretation of this result needs to be interpreted in terms of the theory of diffusion of eco-innovation. The reason lower prices are linked to increased market demand can be interpreted as lower prices affect regulation push and technology push. For customers who need to meet environmental regulations, the low price of new environmental technologies can act as a technology push. Of course, new environmental technologies should have "technology superiority" and "technology reliability."

The quantitative research in Chapter 4 shows that competitive advantage in target markets can increase the probability of commercializing environmental technologies 3.8-fold. Companies can improve their performance (mainly economic performance) based on their "competitive positioning" (Hooley *et al.*, 2001). A company's competitive positioning is created based on marketing assets and marketing capabilities. More specifically, the company's reputation, branding, customer relationships, price, quality, service, and degree of customization offered to the customer can help the company gain a competitive advantage in market offerings. According to the qualitative analysis in this thesis, the "competitive positioning" of a company in its target market is based on the customer relationship of the existing business, making it easier to achieve early commercialization than the competition. A company's technology that has "competitive positioning" in the target market is perceived by the customer as a superior technology.

6.2.4 Environment Characteristics

Environmental factors are factors that have a positive influence on commercialization of environmental technologies that have been supplemented through qualitative research.

Tightening environmental regulations may well create opportunities for new environmental technologies (Kemp, 1997). New technology opportunities refer to the need for incremental improvements in end-of-pipe technologies that result from new environmental protection policies including greenhouse gas reduction policy and PM (particulate matter, often called fine dust) reduction policy- and tightening environmental regulations (reduction of pollutant emissions at production plants). Stricter environmental regulations expand market potential. In addition, the government's subsidy programs to introduce new environmental technologies to businesses contribute to the expansion of market demand. For example, new environmental protection policies, such as reducing PM and reducing VOCs in urban areas, can create new environmental market demands. Based on environmental protection policies, companies can generate initial sales of new environmental technologies relatively easily. In addition, the strengthening of environmental regulation can serve as a stimulus for continued sales growth in all environmental technology sectors. However, the findings of this thesis suggest that the impact of environmental regulations on market demand generation may vary by environmental technology sector. For example, “environmental regulation” does not prove to be a key factor in the quantitative research results. Korea has a mature, large environmental market and a well-established environmental regulation system in the water management, air-quality, and waste management/recycling sector. As a consequence, the “technology push” factor in the main environmental sectors drives the commercialization process rather than the “environmental regulation” factor, at least in the early stages. In terms of environmental technology commercialization, the factor of technology push is related to “technology superiority” and “technology reliability.”

SMEs with limited resources can improve “technology superiority” and “technology reliability” in the process of new product development after the development stage (follow-up R&D, field test, etc.), based on government-supported policies (in particular, R&D subsidies, low-interest loans, etc.).

In conclusion, strong market knowledge, technical superiority, and technical reliability increase the likelihood of commercialization of environmental technologies by SMEs. A company can obtain operational performance through initial commercialization success of new environmental technologies. This is the basis for cooperation with external organizations in the commercialization process and can be a key advantage in the environment market where there are many competitors. In addition, if a company's competitive advantage in the market and the demand of the market are supported, the potential of initial commercialization may be increased. Technological synergy with the company's existing technology, technical services, broad application, top management commitment and support, and government support policies serve as catalysts for strong technology superiority and reliability. The “environmental regulation” factor requires further explanation. According to the convergence results in Chapter 6 this factor does not prove to be a key factor. Rather, the technology push factor led to commercialization of new environmental technologies.

The integrated environmental management system[28] introduced in Korea in 2017 can

[28] Korea benchmarked the EU's integrated environmental management system (e.g. Integrated Pollution Prevention and Control (IPPC) Directive 96/61/EC, Industrial Emissions Directive 2010/75/EU) and enacted the “Act on the integrated control of pollutant-discharging facilities”, and has been implementing the integrated permit system step by step since 2017. The integrated permit system requires companies to demonstrate the

mutually reinforce the factors "environmental regulation" and technology push. The BREF (reference to BAT, Best Available Techniques) provides the types of best available techniques for each industry sector, the achievable environmental performance, and provides technical and economic information. Technical information includes the types of technologies applicable and predictable emissions. For example, the BREF suggests associated emission limit values (ELVs) based on the application of various best available technologies. The goal of the integrated permit system centered on BAT is to introduce new environmental technologies as the best available technology through the BREF, which will lead to the enhancement of the ELVs. Through this, "environmental regulation" and "technology push" factors can be mutually reinforced.

The answers to the research questions and the final conclusions in this thesis are explained in Chapter 7.

application of BAT (best available techniques) in the integrated permit process. BAT refers to the most effective and economical application technology and operation method to reduce the emission of pollutants.

CHAPTER 7: Conclusions

This study contributes to literature and practice: first, the result of this study adds environmental technology as a specific sub-field to existing research areas on technology commercialization. Based on the findings of this study, the author proposed a preliminary model for commercialization of new environmental technologies. This model is a first attempt to comprehensively understand which factors contribute to environmental technology commercialization from the technology provider's perspective. Second, this study provides stakeholders with insights into the commercialization of environmental technologies in SMEs. Chapter 7 presents the contributions, conclusions, limitations, and recommendations of this study.

7.1 Research Contribution

This study aimed to obtain academic and policy insights through understanding of SMEs' commercialization process of environmental technologies. More specifically, it provides a comprehensive understanding of the key factors and the mechanisms which link these factors that influence SMEs commercializing new environmental technologies. Based on this, the author suggests academic and policy implications.

7.1.1 Academic Implications

Based on the existing research on new product performance and technology commercialization, the author came to understand the significant factors and mechanisms of supply of environmental technologies by SMEs. This study adds environmental technology supplies as a specific sub-field to existing research on new product performance and technology commercialization. In addition, the author proposes a comprehensive framework for new product development in environmental technology. It is based on the insights in the process of commercializing environmental technology derived from the research in this thesis.

Research on new product performance and technology commercialization (Brown & Eisenhardt, 1995; Balachandra & Friar, 1997; Krishnan & Ulrich, 2001; Loch & Kavadias, 2008; Datta *et al.*, 2014) has been done to obtain insight into why some new products succeed and others fail. For example, Deshmukh and Chikte (1980) developed a framework for the new product development process based on decision theory, focusing on resource allocation to R&D and commercialization activities. Brown and Eisenhardt (1995) proposed a communication web model that emphasizes the characteristics of the company's top management and its ability to communicate. Krishnan and Ulrich (2001) developed a framework that includes three basic elements of decision making on new product development: product performance (market, design), organization and supply chain, and portfolio selection decisions. However, these frameworks highlight specific theories and phenomena within new product development, but do not aim at a comprehensive perspective.

As mentioned in subsection 2.2.1, there are no researches presenting a theoretical framework for a comprehensive understanding of new product performance or technology commercialization. Loch and Kavadias (2008, Chapter 1) pointed out in the integrated theory study on this topic that new product development theory does not exist and there is no consensus on whether it exists. According to Loch and Kavadias (2008, Chapter 1), new product development has been studied from various disciplines in different areas according to the researchers' needs. In other words, commercialization of innovation is dealt with in many areas, including management, marketing, entrepreneurship, economics, and strategy, and each field has its own research agenda and its own variables, making it almost impossible to see comprehensive views (Datta. *et al.*, 2014). Accordingly, the author of this thesis presents a conceptual framework based on the empirical evidence of previous research on new product performance and new product development process frameworks derived from that research (subsection 2.2.1.2.3). In addition, in order to consider the characteristics of environmental technology in the new product development process, the determinants presented in the study of environmental innovation diffusion (Green *et al.*, 1994; Kemp, 1997; Rennings, 2000) were added to the conceptual framework.

This study found 12 factors that influence the commercialization of environmental technologies of SMEs. In addition, the mechanisms were presented. The author suggests the following implications based on insights on environmental technology commercialization.

First, this study proposed 12 factors that influence commercializing environmental technology. The author was able to complement the identification of success factors and understand the mechanism through simultaneous progression of quantitative and qualitative studies. For example, "technological synergy," "top management commitment and support," "market research skills," and "government support policy" contribute to environmental technology commercialization by supporting other factors. These factors help “technology superiority” and “technology reliability,” which are key factors for environmental technology commercialization. Based on the findings of this study, the author proposed a preliminary model for commercialization of new environmental technologies. This model is a first attempt to comprehensively understand which factors contribute to environmental technology commercialization from the technology provider's perspective (subsection 7.2.2). However, more research is needed to test and extend the findings of this study to develop a reliable model for the commercialization of environmental technologies.

Second, this thesis identified mechanisms of environmental factors (e.g. policy, regulation) in the commercialization of environmental technologies.
In the research on diffusion of environmental innovation, regulatory push and policy pull have been identified as determinants. According to existing literature, strict environmental regulations provide an opportunity for new technology needs (Kemp, 1997) (it refers to the need for incremental improvement of end-of-pipe technologies) by creating new environmental markets and expanding market demand. The qualitative study of this thesis has shown that new environmental regulation policies, such as reducing emissions of PM and VOCs in urban areas, create new environmental market demands. In addition, it was confirmed that the strengthening of environmental regulations played a role in promoting continuous sales expansion in all environmental technology fields. However, this thesis confirmed that the impact of “environmental regulation” on market demand generation may vary by environmental technology sector. For example, “environmental regulation” does not prove to be a key factor influencing commercialization, following the quantitative research results. This might be explained by the fact that Korea has a mature, large environmental market and a well-established environmental regulation system (e.g. water management, air-quality, and waste management/recycling sector). As a consequence, the technology push factor (product quality, material efficiency, energy efficiency) (Rennings, 2000) drives the commercialization process rather than the “environmental regulation” factor, at least in the early stages. In terms of commercialization of environmental technology, the factor technology push is related to “technology superiority” and “technology reliability.” The conclusion provided above can be briefly stated as follows. First, commercialization of environmental technologies in the mature system of environmental regulation is dominated by the influence of technology push factors. Second, strict environmental standards can be a positive factor in its own right.

7.1.2 Policy Implications

This study began with the question why some projects on new product development by SMEs succeeded in commercialization while others failed. This thesis provides an understanding of the key factors and mechanisms which influence the commercialization process. Based on insights in the commercialization process of new environmental technologies, the author derives implications for policymakers in R&D policy and government-supported R&D program management process.

According to the convergence results in Chapter 6, the factor "environmental regulation" has not been proven to be a key factor in the commercialization of environmental technologies in Korea. Specifically, it can be said that in Korea, in the early stages of commercialization, the technology push factors are more important than the "environmental regulation." Policy makers need a shift in the way they consider environmental regulations in the planning of commercial-R&D programs in the environmental sector. Particularly, mutual cooperation between R&D policy and the application of the principle of best available technology (BAT) in the integrated environmental permit system is important. From the perspective of strengthening the competitiveness of environmental technologies, the application of BAT can contribute to the development of pollution reduction driving techniques, pollutant treatment equipment and elementary technology, and expanding market potential.

The project management process of the environmental technology development program in Korea consists of a planning, management and evaluation phase (see table 1.1). The evaluation criteria for current government-supported programs toward commercialization of R&D include research feasibility (necessity, domestic and overseas technology status) and target adequacy, research content (relevance with policy goals, environmental protection linkage), implementation plans (achievement of target, adequacy of promotion plan), R&D performance, human resource availability, and ripple effects (performance plan, commercialization plan, utilization of technical manpower, expected ripple effect). These selection criteria need to be supplemented with criteria on "technology superiority," "technology reliability," and market research capability or market knowledge, which are considered to be the key determinants of commercialization of environmental technology. Evaluation criteria related to "technical superiority" may include differentiation from competitive technology, ease of application, economic advantages for users, and price advantages. In particular, the environmental technology of the sector where the market is already formed and the environment regulation system is well established should be considered an important evaluation item, such as solving the problems of the existing technology, distinctly high pollutant treatment efficiency or economic benefit to customers. “Technology superiority” is more important because the success of early commercialization of environmental technologies in these sectors can be determined by market logic (this refers to a market environment that can be motivated by common business goals such as profitability or product quality improvement.).

In addition, the criteria should be added on a company's capacity to take advantage of “technological synergy”. Companies can improve “technology superiority” and “technology reliability” through “technological synergy,” and “technology superiority” can be the basis of “broad application.” In addition, the project for the development of environmental technology systems should consider the company's visible plans related to “downstream alliance partnerships” in the commercialization plan.

According to the findings of this thesis, the main factors influencing negatively commercialization of environmental technology are low technology completeness and low technology reliability. In the project management phase, the program operator needs to supplement the evaluation of the technology completeness and the technology reliability through intermediate and final evaluations. Evaluation criteria for technology reliability may include field tests, pilot tests, and actual technical verification.

7.2 Answering the Research Questions

7.2.1 Research question 1: Which factors influence the commercialization of environmental technologies by SMEs?

The author found twelve factors that contribute to SMEs' commercialization of environmental technology (see Table 7.1).

Table 7.1

Factors influencing for Environmental Technology Commercialization by SMEs

Dimension	Factors
Technology characteristics	Technology superiority, Technology reliability, Technological synergy, Broad application
Organization characteristics	Market research skills, Top management commitment and support, Good technical service, Downstream alliance partnership
Market characteristics	Competitive intensity, Competitive positioning
Environment characteristics	Government support policy, Environmental regulation

In particular, "technology superiority," "technology reliability," "market research skills," "competitive intensity," and "competitive positioning" factors were identified as key factors, as was shown in the statistical-quantitative studies. The results of quantitative research were verified through qualitative research. The qualitative findings added the following factors: "technological synergy," "broad application," "downstream alliance partnership," "good technical service," "top management commitment and support," "environmental regulation," and "government support policy".

The definitions of the factors identified in the thesis are as follow:

"Technology superiority" encompasses differentiation from competing technologies, ease of application, economic advantages for users, price advantages, technical performance, and technology completeness. In particular, the following factors can be attractive to customers considering the purchase of new environmental technologies: strong technical competitiveness, differentiation from existing technology, problem solving of existing technology (allowing previously impossible work).

"Technology reliability" is defined as the stable operation and legitimacy of new environmental technology systems. Since the environmental technology system is applied to the back-end of a large production process, customers basically want to purchase a technology that has proven completeness and technological reliability. Legitimacy means always meeting environmental regulations.

"Technological synergy" represents the improvement of an environmental new product's technological superiority (e.g. obtaining excellent production technology, quality improvement) by building on a company's process operation expertise, technical expertise, and source technology.

"Broad application" is defined as various applications, diversification of demand.

The company's "market research skills" are included as identification of customer needs and well-planned R&D.

"Top management commitment and support" is determined by the input of resources (e.g. human and financial resources) needed in subsequent R&D (e.g. quality improvement, field tests, and technology verification), mass production, and marketing processes in an SME environment that lacks economic capacity. Top management needs to accept economic risks.

The factor "downstream alliance partnership" includes "cooperation with external organizations across the value chain (e.g. establishing a commercial consortium with mid- or large-sized enterprises)" and "sales outsourcing."

"Good technical service" is defined as a good technical service for customers (including customer training).

"Competitive intensity" represents the presence of many competitors in target markets. The presence of many competitors in existing markets can drive down the market price of technology, which can lead to increased market demand. For example, a drop in the price of an ET system can extend technology customers from large enterprises to mid, small businesses.

"Competitive positioning" is defined as customer confidence based on corporate competitiveness in the target market.

"Government support policies" represent a support policy targeting technology suppliers and market customers. Government support policies for technology suppliers (corporate) include subsidies and low-interest loans. Support policy targeting market demand means subsidies and low-interest loans paid to customers of new environmental technologies.

"Environmental regulation" includes stricter environmental regulation and new environmental protection policies (e.g., GHG reduction policy, PM reduction policy, VOCs reduction policy in urban areas, etc.).

7.2.2 Research questions 2: How are the factors that influence the commercialization of environmental technologies by SMEs interrelated?

In Korea, commercializing environmental technologies by SMEs is influenced by three mechanisms of factors (technology, market, and organization). The factors of the three clusters can be moderated to some extent by "government support policy" and "environmental regulation." The answer to the second research question in this study is described in the following four sub-sections: technology, market, organization, and environment-related factors.

▪ **Technology-related**

The most fundamental factors in the commercialization of environmental technology are the technology characteristics "technical superiority" and "technical reliability." SMEs need to have an innovative edge in order to compete with large companies and succeed (Schumpeter, 1982; Davidsson, 2004). Environmental technologies involved in incremental innovation already have many competitive technologies in the market. Accordingly, the following factors can be attractive to customers who are considering purchasing new environmental technologies: Strong technical competitiveness, differentiation from existing technology, problem-solving for existing technology (enabling previously impossible work). In the qualitative research of Chapter 5, factors such as problem solving of existing technologies, very strong processing efficiency, and reduced operating costs all worked as strong technology push factors.

Since the environmental technology system is applied to the back-end of a large production process, customers basically prefer a technology that has proven superiority and reliability. For example, in an exhaust gas filtration system applied to a thermal power plant, if a problem occurs in the ET system during power generation, all processes must be shut down, which can have a major economic impact. New environmental technologies must always be proven to meet environmental regulations.

Companies can improve the "product superiority" and "technology reliability" of new environmental technologies through building on process operation expertise and source technologies and thus enter the market faster than their competitors (i.e. "technological synergy"). In addition, it is relatively easy to succeed in the initial commercialization by connecting environmental technologies to the following process of the company's existing system.

Based on the process operation expertise and "technology superiority", a company can extend its scope to other areas beyond the target market (it refers to "broad application" in this thesis). The technology commercialization process is very complex and can be influenced by a combination of factors (Datta et al., 2014), which allows a company to flexibly respond to changes in the market environment (e.g. changes in government environmental policies and changes in social environmental issues) during the commercialization process through a "broad application." The acquisition of new customers based on the "broad application" enables the continuous expansion of sales of new environmental technologies.

▪ **Organization-related**

The factors "technology superiority," "technology reliability," and "top management commitment and support" closely affect each other. The top management should presuppose the superiority of development technology to invest in subsequent R&D, and this investment has a positive effect on technology reliability. "Technology reliability" again affects top management's investment decisions in mass production and marketing.

Companies can provide "good technical service" such as optimal process proposal, operation effect verification, and after-sales service training program to consumers based on process operation expertise, technical expertise and source technology. In this process, "good technical service" contributes to the improvement of "technology reliability" and "competitive positioning" in the company's target market.

The establishment of a commercial consortium with large or medium-sized companies (refers to "downstream alliance partnership" in this thesis) can complement customer relationships and the acceptance of economic risks in the process of commercialization. In particular, for SMEs to commercialize an environmental technology system for large-scale production facilities (e.g. power plants, steel mills, and sewage treatment plants) may require forming a consortium with large or mid-sized companies. Small and medium-sized enterprises can benefit from large enterprises such as network, marketing communication, and relationship mediation. In addition, SMEs can reduce the economic burden required to install and maintain environmental technologies through cooperation with large companies.

▪ **Market-related**

Market knowledge, on customer needs, price sensitivity, market potential, competitive environmental information, environmental regulations, and policy information i.a., requires constant updates throughout the process of new product development. Market knowledge enables an SME to identify problems with existing technologies in the target market and to develop alternatives that better meet customer needs. Identification of customer needs and problems with existing technologies can be the basis for “technology superiority” (e.g., differentiation from existing technology, problem solving of existing technology, allowing previously impossible work). Obtaining information on the business plan of the customer can contribute to the success of the commercialization. It may help in better meeting the needs of customers, and in field testing of the new technology. Well-planned R&D and adequately understanding customer needs can significantly reduce the risk of failure in the commercialization process after technology development. The market knowledge implied by the above is an essential support factor for “technology superiority” and “technology reliability.”

The presence of many competitors in the target market causes the price of environmental technology systems to fall, leading to increased market demand. For example, in the case of VOC treatment systems, competition in the market lowers the price of regenerative thermal oxidizer systems, which in turn potentially increases market demand. Specifically, the demand for environmental technology has expanded from large and medium-sized companies to small and medium-sized enterprises. For customers who need to meet environmental regulations the low price of environmental technologies can act as a technology push factor. Of course, environmental technologies should have “technology superiority” and “technology reliability.”

Companies can improve their performance (mainly economic performance) based on their “competitive positioning” (in line with Hooley et al., 2001). According to the qualitative research for this thesis, the “competitive positioning” of a company in its target market is based on the customer relationship of the existing business, making it easier to achieve early commercialization than the competition. A company's technology that has “competitive positioning” in the target market is perceived by the customer as a superior technology.

▪ **Environment-related**

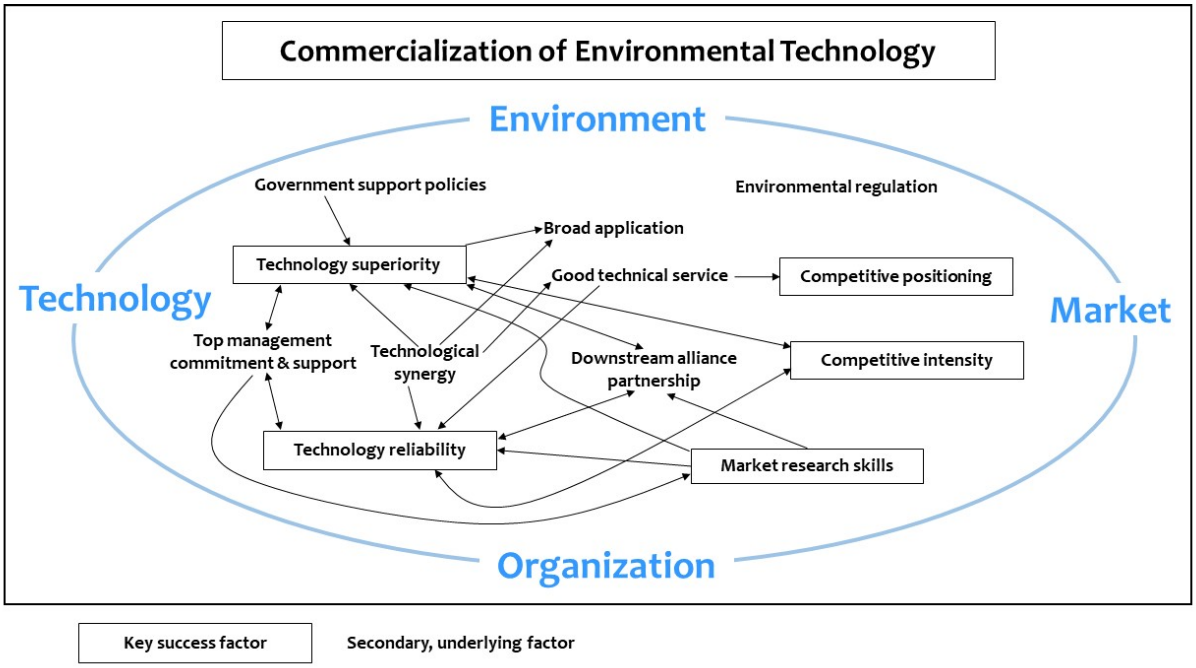
In the qualitative research discussed in Chapter 5, "environmental regulation" creates new markets or expands market potential. New environmental regulation policies, such as reducing PM and VOCs in urban areas, create new environmental market demands. The stricter environmental regulations play a role in promoting continuous sales expansion in all environmental technology fields. This thesis confirmed that the influence of “environmental regulation” on market demand generation may vary by environmental technology sector. “Environmental regulation” does not prove to be a key factor in the quantitative research results. According to the convergence results in Chapter 6, “environmental regulation” contributes little to the initial commercialization process of environmental technologies. Korea has a mature, large environmental market and a well-established environmental regulation system in the water management, air-quality, and waste management/recycling sector. As a consequence, the technology push factor drives the commercialization process rather than the "environmental regulation" factor, at least in the early stages. In terms of environmental technology commercialization, the factor of technology push is related to "technology superiority" and "technology reliability." However, strict environmental standards can be a positive factor in their own right.

SMEs with limited resources can improve "technology superiority" and "technology reliability" in new product development after the development stage (follow-up R&D, field test, etc.), based on government-supported policies (in particular, R&D subsidies, low-interest loans, etc.).

Based on the findings from the quantitative and qualitative phases of the study, a preliminary model of environmental technology commercialization was developed (see Figure 7.1). This model includes factors that influence the commercialization of environmental technologies. The factors that significantly contribute to commercialization of environmental technologies are in square boxes. The other seven factors are secondary and underlying. The arrow-lines represent the interrelationship of factors in the environmental technology commercialization process. This model is a first attempt to comprehensively understand which factors contribute to environmental technology commercialization from the technology provider's perspective. It was limited to environmental technologies developed by the support of government-supported R&D programs in Korea, which has a mature system of environmental regulation. More research is needed to test and extend the findings of this study to develop a reliable model for the commercialization of environmental technologies.

Figure 7.1

Model of Commercialization of Environmental Technology



7.3 Limitations

This study has some limitations.

First, the results of this study are limited to environmental technologies developed by government-funded R&D programs in Korea. There are many promising incremental environmental technologies in the market that do not require government support. In addition, empirical data for this study were provided only in Korea.

Second, environmental technologies in this thesis are limited to end-of-pipe and environmentally friendly process technologies that can be classified as incremental innovations. It does not cover radical eco-innovations, such as energy innovations, which are generally recognized as a tool for sustainable development. This is because it is outside the scope of support for the environmental technology development project. In addition, radical eco-innovation requires more research from the perspective of diffusion of innovation.

The above settings are exactly in line with the research purpose of this thesis, but act as a limiting factor in generalizing the research results.

Third, the existing statistical-deductive studies related to the success factors of technology commercialization have a problem of low participation rate of samples where commercialization failed (Balachandra & Friar, 1997). The quantitative study of this thesis also has these limitations. Of the total target population, 62 projects did not participate in this thesis; 62% of those projects failed to proceed with commercialization. The low participation rate of failure cases can be considered a weakness of this thesis. On the other hand, the powerful validity of the results of convergent parallel design is the strength of this study, which can somewhat offset these limitations.

Fourth, as this study targets projects that have successfully completed government-funded R&D in the environmental field, the number of participants in quantitative studies may be relatively insufficient. In this thesis, 15 explanatory variables were considered in the regression analysis. According to Harrell (2001), more than 150 samples are needed to account for 15 explanatory variables, while the actual number of cases was lower, namely 133 samples. However, this thesis compared and contrasted the results of quantitative research with the results of qualitative research to secure the validity of the overall research.

7.4 Recommendations for further research

First, this study suggested a preliminary model for the success of new environmental technology commercialization. More research is needed to expand and test the findings of this study to develop a reliable model.

Second, the study focused on the success of early commercialization of new environmental technologies. However, in terms of sustainable development and economic development, it is important to enter the overseas market for developing countries. Additional understanding of the environmental technology's entry into the global market and the ongoing revenue-generation process may be required. Subsequent studies may be appropriate for a small sample case study based on qualitative data that tracks the process from initial commercialization to continuous revenue generation.

Finally, this study provided insight into the process of commercializing environmental technology of SMEs in terms of technology suppliers. The Korean Ministry of Environment is operating various policies to support companies' environmental innovation and foster the environmental industry (e.g., development of environmental technology, nurturing environmental industry, support for overseas market advancement, support for green finance, etc.). Subsequent research is necessary to understand how government support programs for SMEs affect short- and long-term growth of SMEs in the environmental industry.

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Appendix 1

Previous research commercialization success / performance measurement

Financial aspect

Success/performance measure	Method	Researcher
Selection of successful and unsuccessful projects (from a financial standpoint) by respondent (intensity of maize commercialization)	Survey	Martey et al., 2017
Sales share performance	Survey	Abu & Haruna, 2017
Economic performance (firm's turnover a year)	Survey	Seyfettinoglu, 2016
Customer-based success, financial success	Survey	Reese et al., 2016
Results from NP overall return (profitability, market share, etc.)	Survey	Salgado et al., 2017
Product sales	Database research	Pee, 2016
Output performance (market shares, sales volumes, growth rates, profit margins)	Survey	Li & Chen, 2016
Financial dimension (revenue, yield, market shares)	Survey	Jo & Park, 2017
Technology commercialization (financial aspects)	Survey	Mishra & Saji, 2013
Performance of new product after launch (financial aspects, market share, brand strengthening, new competencies)	Survey	de Sousa Mendes & Devós Ganga, 2013
Sales revenue from new product sales	Survey	Emodi et al., 2017
New commercial sales were generated	Survey	Jung et al., 2015
New product performance (market share, sales and customer use, sales growth and profit objectives)	Survey	Morgan et al., 2015
Market performance (selection by respondent) - profitability of the new product is high relative to main competitors - market share of the new product is high relative to main competitors - growth in sales of the new product is fast relative to main competitors	Survey	Kong et al., 2015
new product performance (cumulative sales of each product, which also was available in the division's database)	Survey	Eling et al., 2013
Firm's radical and incremental innovation outcome (firm's financial status)	Database research	Song et al., 2016
Turnover from new products, Average costs reduction	Database research	Guzzini & Iacobucci, 2017

Non-financial aspects

Success/performance measure	Method	Researcher
Market launch	Database research	Wagner & Wakeman, 2016

Commercialization success - market launch of a molecular drug	Database research	Dutta & Hora, 2017
Count of successes in technology innovation commercialization (launch of final product results)	Database research	Hora & Dutta, 2013
Market approval rate/length market approval delay, Number products submitted	mixed methods (qual → Quan)	O'Dwyer & Cormican, 2017
Technology commercialization, firm performance - patents, introduce many products to the market	Survey	Park & Ryu, 2015
Selection of successful and unsuccessful commercialization by respondent - your company takes the lead introducing new products - company's innovative success rate is higher compared with peers	Survey	Zhao et al., 2017
Technology commercialization performance (the number of new products, time to new product, and market futures)	Survey	Lin et al., 2015
- New to market - Abandonment during conception and development phase	Survey	D'Este & Olmos-Penuela, 2016
Selection of successful and unsuccessful projects by respondent (greater than 3.5 in the survey-based on the five-point Likert rating scale)	Mixed methods (qual → Quan)	Kachouie & Sedighadeli, 2015

Financial / Non-financial aspect

Success/performance measure	Method	Researcher
Customer-based performance (a new product launched) / Financial-based performance(profitability)	Survey	Heirati & O'Cass, 2016

Appendix 2

Item list and measurements

Dependent variables

Technology commercialization success/failure	Has your development technology been released to the market, generating revenue? (yes, no)

Independent variables

Technology characteristics

Product superiority	How do you rate your level of technological competitiveness of the development technology in the target market? (Technological competitiveness includes customers' economic benefits, strong performance, ease of implementation and price competitiveness.) (1 = very low level, 5 = very high level)
Technology reliability	Has the development technology been proven legitimacy? (e.g., field test results, operational performance reference, third-party verification, etc.) (yes, no)
Technological synergy	Do you have the skills to increase the market value of your development skills? (e.g., technology engineering, source and complementary technologies, related patents, etc.) (yes, no)
First to market	Is there an alternative or competitive development technology in the target market? (yes, no)

Organization characteristics

Top management commitment and visible support	How do you rate your level of “top management commitment, visible support” (e.g., follow-up R&D and commercialization investment, interest in project, willingness to pursue, etc.) for new projects? (1 = very low level, 5 = very high level)
Market research skills	How do you rate your level of "market research skills" of the company? (market research skills include market assessment, market research, potential research, market competitiveness research, etc.) (1 = very low level, 5 = very high level)
Marketing proficiency	Does your company have experience in commercializing new technologies? (yes, no)
Human resources dedicated to R&D	What is the proportion of dedicated personnel in the organization for research and development? (ratio, %)

Human resources dedicated to marketing	How do you rate your level of professional manpower for marketing? (1 = very low level, 5 = very high level)
R&D funding	How do you rate your level of economic resources for subsequent R&D and production? (1 = very low level, 5 = very high level)
Marketing funding	How do you rate your level of economic resources for the commercialization of development technology? (1 = very low level, 5 = very high level)
Financial accessibility	Where did you source the funds for the commercialization of your development technology? (internal, public sector, private sector)
Identification of customer needs	How do you rate your level of understanding of the needs of customers in the course of technology development and commercialization projects? (1 = very low level, 5 = very high level)
R&D collaboration	Has there been cooperation with external organizations (e.g. research university, public side research institute) during the technology development process? (yes, no)
Cooperation with customers	Was there customer involvement or cooperation with the customer during technology development? (yes, no)

Market characteristics, Environment characteristics

Target market size	What is the target market size or level of market potential associated with the development technology? (1 = very low level, 5 = very high level)
Uncertainty (market/technology)	How is the level of uncertainty in technology development and commercialization in relation to development technology? (1 = very low level, 5 = very high level)
Competitive positioning	How competitive is your company’s position in the target market? (Competitive position in the target market can be judged by your company’s reputation, branding, and customer relationships.) (1 = very low level, 5 = very high level)
Competitive intensity	How is the level of competition intensity in the target market? (1 = very low level, 5 = very high level)
Government support policies	After your government-funded R&D, have you benefited from the government’s support policies (e.g., subsequent R&D funding, commercialization funding, subsidies for technology adoption, etc.)? (yes, no)
Relevance to environmental	How relevant is the development technology to the customer’s response to environmental regulations?

regulations	(1 = very low level, 5 = very high level)
Level of environmental regulations	What is the level of environmental regulation associated with development technology? (1 = very low level, 5 = very high level)

Appendix 3

Results of open coding

10 Successes projects

Quotations	Open coding
Case 1	
When using the existing technology for more than 6 months, leakage occurs and the treatment efficiency is 95%. So, it is difficult to meet environmental regulations. However, since the valve type has few leaks, it can maintain high treatment efficiency continuously.	Durability of technology is excellent, the processing efficiency of VOCs is high, and it lasts.
Solenoid valves and actuator valves produce consumable parts in the device during use. The consumables can be replaced on their own.	Easy to maintain and manage after applying technology on the customer side.
Recently, as environmental regulations related to fine dust have been strengthened, in the case of domestic VOC emission sites, emission standards are not met. As a result, demand for mid-sized companies is increasing.	Environmental regulations related to VOCs drive market demand.
As market competition in related fields is intensifying, the price of VOCs processing systems is lowering overall. As a result, market demand in this field has increased. In addition to the reduction of VOCs, the reduction of operating costs due to heat recovery is helping to expand the market of related technologies.	High competition intensity → the market price of technology has decreased → increase in market demand Users economic advantage
Public institutions provide facility loans to businesses every year. Companies with collateral are using the funds.	Government support policy drives technology demand(Market expansion effect)
We have built up a career in this area and have been able to make continuous improvements in efficiency.	Continuous technical improvement based on the company' technological know-how
We have made a lot of technical improvements through government supported R&D projects.	Government-supported R&D enabled us to supplement technology a lot.
In general, it is true that the cost of introducing our technology is higher than the economic advantage of saving energy. However, if VOCs that are difficult to decompose can be removed, the cost burden is not a problem. It can be enough motivation for customers to remodel existing removal devices. In the case of RTO technology which is widely applied in the market, treatment efficiency of VOCs is about 95 ~ 98%, and when the partial technology of the system developed through this project is applied, treatment efficiency of 99% or more is	Removal efficiency of VOCs that are difficult to decompose / VOCs removal efficiency superior to existing technologies

Quotations	Open coding
achieved. *RTO; Regenerative Thermal Oxidizer	
Case 2	
We successfully commercialized the developed technology by applying it to other fields (HAPs emission reduction device). We have signed contracts with various companies in Korea and overseas and are expanding our business. *HAPs; Hazardous Air Pollutants	Successful commercialization by applying to other field
In the case of VOC recovery technology, commercialization is being carried out with institutional support in the target market. However, institutional support is not enough to expand the business. The application field to HAPs processing equipment is expected to increase sales in the future as environmental regulations are strengthened.	Successful initial commercialization based on government institutional support Increased sales based on strengthening environmental regulation.
Commercialization of the technology developed through the government support project was commercialized by applying it to the downstream process of existing business. We are currently marketing to Italian companies.	Linking with existing business (applying downstream process) to promote commercialization.
We have been doing it for 12 years from the beginning of technology application. I think our company has the world's best technology in this field. Although not officially verified, our technology is more efficient at recovering VOCs compared to foreign technologies. As efficiency increases, competitiveness is secured.	Compared with overseas competition technology, high VOC recovery efficiency
Price competitiveness was important. Of course, efficiency is absolutely critical to apply to HAPs treatment. The technology developed through the government support project is the equipment related to the recovery of VOC, and it has been applied to the HAPs processing facility by expanding the scope of application.	High price competitiveness Expansion of technology coverage based on high technical performance.
The reason why the market is not expanding is because it needs institutional supplementation from the government. Currently, we are selling with economic logic. If the installation cost is $ 20,000, you need to save $ 20,000 over two years through efficient operation of the process.	Successful approach to commercialization with initial economic logic (Reduction in operating costs after applying technology from the customer side)
Process management know-how was secured through after-sales service of existing business. Based on this, it was able to commercialize in other fields.	Expansion of application scope based on know-how of process operation of developed technology.
case 3	
In the case of commercialization targeting large corporations,	Through the consortium of

Quotations	Open coding
there are entry barriers. In case of problems in the process after technology application, large companies do not trust SMEs in terms of problem-solving ability. In other words, large firms consider not only the reliability of technology but also the economic size of the supplier. “A” medium-sized company has signed a maintenance contract with “B”. So even if there is a problem with the new product, “A” company is responsible. We are supplying ET systems to large companies with "A" company.	commercialization with mid-sized companies, it was possible to deal with large companies.
Developed countries' technology in this field is not applicable to developing countries. There is a problem with maintenance, throughput, etc., for use in developing countries. The technology we have developed is highly satisfying in developing countries. Demand for cement is increasing in developing countries. In other words, the future demand forecast of our technology is bright.	Developing technology considering user's environmental characteristics (Applied to areas where technology of advanced countries is difficult to apply)
	Commercialization of partial technology that is easy to apply to existing facilities
When applying this technology (element technology) to the existing equipment of the customer, operation cost is reduced and VOCs processing efficiency is greatly improved.	Reduce operating costs and improve processing efficiency when applied.
Our company performed follow-up R&D after government-supported R&D project termination. As a result, the company is expanding its business with continuous technological improvement.	Improvement technology through continuous technology development
In the case of our company, after the end of the government-funded R&D project, we invested a lot of money (factory and production investment).	Subsequent research and investment in facilities by top executives
Case 4	
Since the facilities used in the process of electronic companies are expensive, the customer does not intend to use cheap domestic devices in the case of measuring instruments used in the intermediate process. So we are commercializing it in a way that it supplies measurement equipment to other fields(Semiconductor equipment market → semiconductor industry, plating, machinery ・ metal).	Commercialization through diversification of demand
For our products, gauge reproducibility is 1%. In the case of the technology used in the market, the measurement reproducibility is 3 to 5%.	Technological advantage over market's advanced technology (existing technology)
For the developed measuring device, the price is about $20,000. It is 70% of the price of measuring equipment in advanced countries now being used in the market. Customers	Low cost compared to the market's existing measuring equipment

Quotations	Open coding
have 30% cost savings when applying our technology.	
Our company is a company based in the chemical industry. In other words, it is easy to apply a prototype of a measuring device.	Ease of development and application (Based on its owned technology)
Case 5	
This technology can solve the insufficient parts of the devices used in the existing market. By applying our technology, the treatment effect is greatly improved. This technology has a technical advantage over other technologies in the livestock manure processing sector. We can recognize it in the field. In the past, it took 30 hours to process livestock manure. However, if we apply our technology, it can be processed in 15 hours. In terms of processing efficiency, we are competitive.	A technology that can compensate the problems of the facilities that are currently used in the market Technical competitive advantage
Government-supported R&D project was sewage / wastewater treatment technologies. However, based on this, it was applied to livestock manure treatment areas and succeeded in initial commercialization. This technology was applied to the livestock manure disposal field, and it was possible to commercialize it in the early stage because the processing efficiency was higher than existing facilities.	Obtaining new customer information on the part technology (system part device)
Applying this technology to sludge thickening has a great effect on sludge reduction. If the customer applies a trial, the effect can be seen directly. These demonstration operating results are very helpful for marketing.	Obtaining operational proof → sales (base for sales expansion)
Case 6	
In the case of conventional small-scale sewage treatment plants, there are many difficulties in applying biological treatment due to differences in the amount of water treated in summer and winter. When the system developed through the government support project is applied, operation management is easy and the processing efficiency is good. In general, when a membrane is used, clogging often occurs during operation of the process. In order to compensate for this clogging, we developed our own back washing process. Through this, we have developed membranes and fully productized the product housing.	Access through technology development that can solve problems of existing processing methods. Developing technologies that can solve the problems of sewage treatment methods used in the market.
We have developed our own production method to complement the economic advantages of ceramics. Through this development, it has superior characteristics and lower product price than existing products. If the technology of an overseas company pulls out 850 liters, our technology can pull up to	Company's technology linkage → development of production method → characteristic excellent, low unit price

Quotations	Open coding
5,000 liters. Flux has been developed well.	
Currently, we are in the process of commercializing the membrane separately. The reason is that commercialization of partial technologies is relatively easy. We did not take all of the system and divided the parts of technology. Because it is commercialized as a part of the whole facility, the risk is less than commercialization of the ET system.	Success in initial commercialization by using parts rather than the whole system.
There will be no company that uses production technology "A" worldwide. Ceramic membrane production technology is easy to change shape and economical to produce.	Holding competitive edge in production technology of core parts → production cost reduction
We have improved our technology through other government support projects. Through additional government-funded R&D projects, high material development costs were reduced.	Government support → enhance the completeness of technology through additional follow-up studies
We have been cooperating with company "B" and are promoting business for environment water treatment and filtration of bio lactic acid bacteria protein membrane.	Expanding business into other fields by cooperating with bigger companies than ours
There is a high demand for mobile wastewater treatment, zero house, and zero toilet. This technology takes about 80,000 US dollars to process 100 tons. Compared to actual sewage treatment plant construction costs, it is less than half the cost.	Ease of installation.
Case 7	
These products are small compared with the existing products used in the market, and they are stable and highly efficient. In addition, the benefits of this product are reduced operating costs by reducing electricity usage.	Technical advantages compared with existing products (miniaturization, reduction of operation cost)
In the case of small and medium pigs, chicken farms, we have to sterilize the animal excrement. This technology is the most effective in this area.	Various applications
This technique is applied to remove odors from composting. Generally, when you remove odor, it is washed away by spraying. The wastewater resulting from this is hazardous waste, which is expensive to dispose of. Applying this technology can reduce waste disposal costs.	Excellence of technology, reduction of user's operating cost
Other companies just buy parts and assemble them. However, our company does a lot of research on source proprietary technology. So after-sales service competency is relatively good. So, the customers acknowledge our technical competence.	Based on the company's know-how, securing high technical reliability for customers
At the beginning of the project, we used inverter transformers	Improving the completeness of

Quotations	Open coding
produced in China, but there were many problems during operation. In-house development of the parts has optimized the equipment such as noise reduction, electricity usage reduction, and miniaturization. Currently, we are competing with companies in developed countries such as Japan and Germany.	technology through subsequent research
We are inviting overseas demand to Korea for export. Developing countries lack operational technical personnel. So, in order to export the technology, we are running an educational program that enables the customer to directly access the after-sales service. Based on these educational programs, we plan to expand our business to Southeast Asia in the future.	Since its initial commercialization, offer of after-sales service education programs for employees of overseas buyers
We propose a process optimized for the customer at the customer site and train the detailed operation method. In addition, operational effectiveness is verified through operations after-sales service.	Optimal process proposal for customer
	Offer of operational effectiveness verification through after-sales service
In the case of SMEs, the most important factor in successful commercialization is the top management commitment to commercialize technology. When there is a willingness of the CEO, follow-up R&D and new technology verification are coming. Basically, you can do business only after the quality is verified.	Top management commitment → follow-up R&D / technology verification → sales
Case 8	
After the research and development, we conducted additional drug tests on our own.	Technical complementation through follow-up research such as drug testing is conducted.
We invested about 9 million US dollars to build and expand the factory. I had to make a set, so I invested in assembling the set directly.	Top management commitment for investing and funding
The technology has been developed to a level that can compete with developed countries. Non-adsorption of the drug was verified by using non-hydrophilic raw materials.	Equivalent to the level of technology in developed countries / Verified technology
Due to the technical advantages, we can get 30-50% more support from the government than existing products. Accordingly, we were able to secure price competitiveness.	Ensuring price competitiveness (Price is important because it is consumable product)
The top management had the source technology, which enabled them to attract investment from outside. We proceeded with technology development and mass production, and outsourced the sales to professional organizations. after-sales service training programs were provided to outsourcing companies.	Holding its own source technology
	Sales outsourcing

Quotations	Open coding
Case 9	
By the end of the government-funded R&D project, we thought our company had the world's best technology.	High level of technology
Our company has the technology of groundwater pollution purification field and has know-how about operation technology.	Holding technical know-how in related fields.
Based on the competitiveness of the company, we are recognized as the best technology in the area of water pollution treatment by local governments and companies. Based on successful operation results, technology promotion was conducted. Based on this, it was possible to sign sales contracts with existing and new customers	Customer confidence based on corporate competitiveness
	Proof of long-term operation results
	Connection with company's existing business (sale, customers).
The technology present in the market blocks the entire contaminated area. We have developed a technology that can selectively block polluted areas through this technology development.	Differentiation from existing technology
Case 10	
The developed technology will be utilized for organic wastes disposal until commercialization of livestock burial land related business is activated.	Success in initial commercialization by applying technology to other fields.
Based on the results of the TEST-BED operation conducted by the government-funded R&D project, we continued commercialization. Technology demonstrations were also conducted for local governments, which are major technology demand centers.	Sales based on operating performance of PILOT scale.
The technology "A" was applied to the field of leachate treatment of buried ground is the technology developed for the first time in Korea. The acquisition of customer information (local government budget, business plan, etc.) has greatly helped commercialization.	Grasp customer information such as budget and business plan.
Government supported R&D projects were able to operate demonstration facilities in local governments. The proof of operation obtained through this has greatly contributed to commercialization.	Government support → Small-scale TEST-BED operation

10 Failures projects

Quotations	Open coding
Case 11	

Quotations	Open coding
Customer confidence is lacking because we do not have commercialization experience in the field related to the developed technology. In addition, we have not been able to carry out further studies to develop scaffolds and verify the technology. We have not been able to carry out commercialization because we have not been able to field test the system for scale-up.	Lack of customer confidence due to lack of experience in technology development and commercialization
	Failure of continually develop technology (scale-up failure)
Customers (e.g., electric power generation enterprise) want to purchase technology that has proof of operation rather than unit price.	No proof of operation
The most important thing in manufacturing high performance filters is price competitiveness. In order to be price competitive, the price competitiveness of the support used inside the filter is important. Currently we are looking for suppliers who can produce cheap and superior supports. If we find such a company, there is a possibility of commercialization.	Low cost competitiveness of parts technology
Our technology is installed in power plants or generating facilities that use renewable energy. Because power generation systems are so large, it is difficult for small and medium-sized companies to commercialize them. In order to commercialize the ET system, a consortium with large companies is necessary. In order to form a consortium, experience (performance) in commercialization in the relevant environmental sector is required. We do not have experience installing or operating such a large facility in the field of air quality. When delivering ET systems to customers, ET systems must be installed, but the cost is high.	No commercialization experience for large-scale ET systems
	Failed to form a consortium with large companies.
	Lack of economic capability to install and operate the system.
Case 12	
Government-supported R&D projects include technologies to recover expensive metals from industrial wastewater. However, wastewater containing high concentrations of metals in the market now sells wastewater itself.	Not a technology that is needed in the market
Although it is a good technology, the customer does not trust it because it is not verified. In addition, there is a need for technical improvement such as corrosion problems.	Failure to field or pilot scale testing
	Technically additional supplement is required.
Industrial wastewater treatment system has a large business scale even if it improves part of the existing system. Thus, the customer requested the formation of a consortium with a medium-sized enterprise or large enterprise in order to reduce the risk of failure after applying the technology. However, we failed to form a consortium.	Consortium configuration failed for commercialization
Case 13	
Commercialization of heavy metal measuring devices is not easy. Our	Lack of verification of

Quotations	Open coding
technology must meet the government regulation standards, so it should be highly reliable, but our technology is not enough.	technology
We do not know who to target. There are companies that proposed joint R&D with us, but there is no company to purchase products. R&D projects are also needed to improve the completeness of the technology, but even if it improves the completeness of the technology, it cannot find a customer who is interested in technology.	Failure to find a customer (Lack of market research capability)
If you have developed a new measuring instrument, you should have comparative data on the measurements with existing instruments on the market. However, our technology was not enough. We could not do business because there was no data to compare the results with existing equipment.	Lack of accuracy check of measuring equipment → difficulty in sales
Case 14	
In the field of nitrogen and phosphorus removal, I think there is a possibility of commercialization. However, the processing speed is slower than existing technologies used in the market. If technological improvements in processing speed are achieved, it will be a little more helpful for commercialization.	Compared with the existing technology of the market, the processing speed is slow (need technical improvement)
We have successfully completed the pilot plant scale test. However, the field test was not proceeding. We do not have a specific field test plan yet, and we expect it to take at least two to three years. It will be possible to do marketing (sales) by securing proof through field tests.	Failed field test → Cannot do marketing.
In terms of economy, our technology is less competitive than the technology used in the market.	Price competitiveness is poor
Case 15	
We abandoned commercialization. Because there are many sludge disposal technologies in the market, customers don't think our technology is useful. Competitive companies in the same sector are offering higher sludge reduction rates. Although we have developed new technologies, we expect operating costs to be higher than expected after applying the technology. Our technology in the market did not receive attention.	Lack of technical competitiveness compared to the technology in the market. High operating costs Lack of customer needs identification Lack of research on competitive technologies in R&D planning
In order to conduct sales, it is necessary to verify the technology through real-scale testing. However, the facility installation cost is too high and there is no demand, so the risk is too great.	There is no willingness of the CEO to take economic risks.

Quotations	Open coding
Case 16	
At present, supply of raw materials is difficult. Currently, power generation public enterprises are sold to disability groups and patriots and veterans organizations when waste wires are generated. Therefore, it is difficult to receive raw materials.	Difficult to obtain raw materials
The goal is to enter the public market. But public corporations are not interested. It would have been helpful if there were prior consultations with the customer at the planning stage of technology development.	R&D planning is insufficient / Lack of understanding of customer needs
Case 17	
Developed fuels are not certified as legitimate fuels by the government, and are not able to enter the market because they are treated as fake petroleum. So it is difficult to further develop (there is not enough institutional basis to legalize developed fuels). The final product of this project should be mixed with conventional petroleum fuels as hydrocarbon fuels.	Inability to enter the market due to lack of policy base or support / Insufficient research on the market environment
After the government-funded R&D project has been completed, no additional pilot plant test or commercial scale test has been conducted. In other words, there is not enough preparation for commercialization.	Lack of completeness of technology
Case 18	
The recent drop in oil prices has caused a significant drop in value added to bioenergy. In order to promote business overseas, we prepared a project for commercialization for two years, but stopped the process due to falling oil prices during preparation. In addition, the economic situation of the company is difficult, and it is difficult to continue to pursue new businesses.	Absence of demand due to changes in the market environment / Market uncertainty
After the government-funded R&D project, there was a technical problem during the pilot plant scale test. When applied to the field, there was difficulty in securing major raw materials.	Problems arise during scale-up of technology
Case 19	
The current technology is the pilot plant test phase. We plan to identify and continuously address the issues that may arise through field testing.	Lack of technical complement
We developed technology by targeting customers in existing businesses. However, as the customer continues to use the existing technology, there is no opportunity for us.	Target customer is not interested in technology (Insufficient understanding of customer needs, insufficient market research)
There are no companies that produce large quantities of porous raw materials used in the production of photo catalyst carriers in Korea. We	Demand and supply of raw materials for

Quotations	Open coding
need to be supplied raw materials for mass production.	product production is difficult.
Case 20	
Government's active involvement in cleanup of groundwater pollution is needed. The market is not well formed due to the lack of government policy support. Currently, there are no plans to commercialize development technology. We are considering commercialization in accordance with the direction of government policies related to groundwater pollution treatment.	The market is not formed due to insufficient government support (e.g., principle of burden of treatment cost of pollutants, etc.).

Appendix 4

Results of Categorization

Categorization of Success projects

	Codes from quotations	Sub-categories	Categories
1	High level of technology (Case 9)	Strong technology competitiveness	Technology superiority
2	Equivalent to the level of technology in developed countries / Verified technology (Case 8)		
3	A technology that can compensate the problems of the facilities that are currently used in the market (Case 5)		
4	Differentiation from existing technology (Case 9)	Product advantage (differentiation over competitive offerings)	
5	Developing technology considering user's environmental characteristics (Applied to areas where technology of advanced countries is difficult to apply) (Case 3)		
6	Developing technologies that can solve the problems of sewage treatment methods used in the market (Case 6)		
7	Commercialization of partial technology that is easy to apply to existing facilities (Case 3)	Product advantage (ease of innovation introduction and implementation)	
8	Ease of installation (Case 6)		
9	Easy to maintain and manage after applying technology on the customer side (Case 1)		
10	Success in initial commercialization by using parts rather than whole system (Case 6)		
11	Technical advantages compared with existing products (miniaturization, reduction of operation cost) (Case 7)	Product advantage (economic advantages of product for users)	
12	Users economic advantage (Case 1)		
13	Reduce operating costs and improve processing efficiency when applied (Case 3)		
14	Successful approach to commercialization with initial economic logic (Reduction in operating costs after applying technology from the customer side) (Case 2)		
15	Ensuring price competitiveness (Price is important because it is consumable product) (Case 8)	Product advantage (lower-price product)	
16	High price competitiveness (Case 2)		
17	Low cost compared to the market's existing measuring equipment (Case 4)		
18	Holding competitive edge in production technology of core parts → production cost reduction (Case 6)		

	Codes from quotations	Sub-categories	Categories
19	Durability of technology is excellent, the processing efficiency of VOCs is high, and it lasts (Case 1)	Product advantage (technical performance)	
20	Excellence of technology, reduction of user's operating cost (Case 7)		
21	Technical competitive advantage (Case 5)		
22	Technological advantage over market's advanced technology (existing technology) (Case 4)		
23	Removal efficiency of VOCs that are difficult to decompose / VOCs removal efficiency superior to existing technologies (Case 1)		
24	Compared with overseas competition technology, high VOC recovery efficiency (Case 2)		
25	Expansion of technology coverage based on high technical performance (Case2)		
26	Technical complementation through follow-up research such as drug testing are conducted (Case 8)	Completeness of technology	
27	Improvement technology through continuous technology development (Case 3)		
28	Improving the completeness of technology through subsequent research (Case 7)		
29	Various applications (Case 7)	Broad applications in diverse market segments	Broad applications
30	Commercialization through diversification of demand (Case 4)		
31	Obtaining new customer information on the part technology (system part device) (Case 5)		
32	Success in initial commercialization by applying technology to other fields (Case 10)		
33	Successful commercialization by applying to other field (Case 2)		
34	Customer confidence based on corporate competitiveness (Case 9)	Competitive positioning	Competitive positioning
35	Expanding business into other fields by cooperating with bigger companies than ours (Case 6)	Cooperation with external organizations across the value chain	Downstream alliance partnership
36	Through the consortium of commercialization with mid-sized companies, it was possible to deal with large companies (Case 3)		
37	Sales outsourcing (Case 8)	Sales outsourcing	
38	Successful initial commercialization based on government institutional support (Case 2)	Environmental regulation relevance	Environmental regulation
39	Environmental regulations related to VOCs drive market demand (Case 1)	High-level environmental standards (or new environmental-protection policies)	
40	Increased sales based on strengthening environmental regulation (Case 2)		

	Codes from quotations	Sub-categories	Categories
41	Government support policy drives technology demand (Market expansion effect) (Case 1)	Government support (low-interest loans)	Government support policies
42	Government-supported R&D enabled us to supplement technology a lot (Case 1)	Government support (R&D subsidies (government support commercial-R&D))	
43	Government support → Small-scale TEST-BED operation (Case 10)		
44	Government support → enhance the completeness of technology through additional follow-up studies (Case 6)		
45	Grasp customer information such as budget and business plan (Case 10)	Identification of customer needs	Market research skills
46	Access through technology development that can solve problems of existing processing methods (Case 6)	Market research skills (well-planned R&D)	
47	High competition intensity → the market price of technology has decreased → increase in market demand (Case 1)	Increased competition intensity	Competitive intensity
48	Offer of operational effectiveness verification through after-sales service (Case 7)	Provide a good technical service to customers (including customer training)	Good technical service
49	Optimal process proposal for customer (Case 7)		
50	Since its initial commercialization, offer of after-sales service education programs for employees of overseas buyers (Case 7)		
51	Sales based on operating performance of pilot-scale (Case 10)	Technology reliability	Technology reliability
52	Proof of long-term operation results (Case 9)		
53	Obtaining operational proof → sales (base for sales expansion) (Case 5)		
54	Based on the company's know-how, securing high technical reliability for customers (Case 7)	Improving technology and reliability based on firm's expertise	Technological synergy
55	Expansion of application scope based on know-how of process operation of developed technology (Case 2)		
56	Holding technical know-how in related fields (Case 9)		
57	Continuous technical improvement based on the company' technological know-how (Case 1)		
58	Linking with existing business (applying downstream process) to promote commercialization (Case 2)	Successful commercialization through linking existing business (applying to downstream process)	
59	Ease of development and application (Based on its owned technology) (Case 4)	Development of derived technology	

	Codes from quotations	Sub-categories	Categories
		based on the firm's technology	
60	Company's technology linkage → development of production method → characteristic excellent, low unit price (Case 6)	Development of excellent production processes based on firm's technology	
61	Holding its own source technology (Case 8)	Possess source technology	
62	Top management commitment for investing and funding (Case 8)	Top management commitment to innovation	Top management commitment & support
63	Subsequent research and investment in facilities by top executives (Case 3)		
64	Top management commitment → follow-up R&D / technology verification → sales (Case 7)		

Categorization of Failure projects

	Codes from quotations	Sub-categories	Categories
1	Failed to form a consortium with large companies (Case11)	Failure to establish a downstream alliance	Downstream alliance partnership
2	Consortium configuration failed for commercialization (Case12)		
3	Lack of economic capability to install and operate the system (Case11)	Lack of financial resources	Financial resources
4	The market is not formed due to insufficient government support (e.g., principle of burden of treatment cost of pollutants, etc.) (Case20)	Lack of government support (policy side)	Government support (policy side)
5	Lack of research on competitive technologies in R&D planning (Case15)	Lack of market research skills (competing technologies, customers, and demand)	Market research skills
6	Not a technology that is needed in the market (Case12)		
7	Failure to find a customer (Lack of market research capability) (Case13)		
8	Inability to enter the market due to lack of policy base or support / Insufficient research on the market environment (Case17)	Lack of market research skills (policy trends and market environment)	
9	Lack of customer needs identification (Case15)	Product does not meet customer needs	
10	R&D planning is insufficient/Lack of understanding of customer needs (Case16)		
11	Target customer is not interested in technology (Insufficient understanding of customer needs, insufficient market research) (Case19)		
12	There is no willingness of CEO to take economic risks	Lack of top	Top management

	Codes from quotations	Sub-categories	Categories
	(Case15)	management acceptance of risk	commitment & support
13	High operating cost (Case15)	Economic disadvantages of the product to the user	Technology superiority
14	Price competitiveness is poor (Case14)	Low level technology competitiveness (price)	
15	Low cost competitiveness of parts technology (Case11)		
16	Lack of technical complement (Case19)	Low level technology competitiveness (technical performance)	
17	Problems arise during scale-up of technology (Case18)		
18	Failure of continually develop technology (scale-up failure) (Case11)		
19	Technically additional supplement is required (Case12)		
20	Lack of technical competitiveness compared to the technology in the market (Case15)		
21	Compared with the existing technology of the market, the processing speed is slow (need technical improvement) (Case14)		
22	Lack of accuracy check of measuring equipment → difficulty in sales (Case13)		
23	Lack of completeness of technology (Case17)		
24	Failed field test → Cannot do marketing (Case14)	Low reliability of technology	Technology reliability
25	Failure to field or pilot scale testing (Case12)		
26	Lack of verification of technology (Case13)		
27	No proof of operation (Case11)		
28	No commercialization experience for large-scale ET systems (Case11)	No experience with similar project implementation	Marketing proficiency
29	Lack of customer confidence due to lack of experience in technology development and commercialization (Case11)		
30	Difficult to obtain raw materials (Case16)	Unavailability of raw materials	Availability of raw materials
31	Demand and supply of raw materials for product production is difficult (Case19)		
32	Absence of demand due to changes in the market environment / Market uncertainty (Case18)	Uncertainty (market)	Uncertainty

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In addition to sustainable development, interest in environmental technology is continuing. According to the German Greentech report, the world market for major environmental technologies (e.g. sustainable water management, waste management and recycling, and material efficiency) represented €1,298 billion EUR in 2016 and is expected to reach €2,259 billion EUR by 2025. Following this trend, the budget for the commercial-R&D program in the South Korean environment sector expands annually. In 2018, the Ministry of Environment provided $129 million USD in R&D projects for the application and development phase. However, the commercialization success rate – defined as market introduction and new sales generation – of commercial-R&D programs supported by the government—in the environment sector— is very low compared to other developed countries.

Through this study, the author provides insight into the commercialization of environmental technology by SMEs. More specifically, it provides a comprehensive understanding of the key factors and the mechanisms that influence the commercializing environmental technologies. In this thesis "environmental technologies" refers to end-of-pipe and eco-friendly process technologies. The theoretical basis of this study is based on a framework for the new product development literature and empirical evidence. To consider the characteristics of environmental technology, the fra
ɪework includes the determinants of eco-innovation.

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