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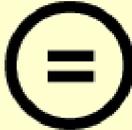
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Doctoral Thesis

Social Construction of the ESS fires in Korea:
Focusing on Social Context Changes and the
Stakeholders' Experience

Dong-Hyeon Im

Department of Urban and Environmental Engineering
(Disaster Management Engineering)

Ulsan National Institute of Science and Technology

2021

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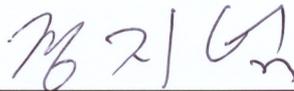
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A thesis/dissertation submitted to
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requirements for the degree of
Doctor of Philosophy

Dong-Hyeon Im

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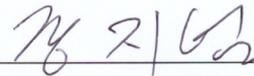
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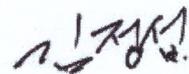
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Abstract

Social Construction of the ESS Fires in Korea: Focusing on Social Context Changes and the Stakeholders' Experiences

by

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This dissertation deals with the relationship between continuous fire accidents in ESS and social factors that affected the fire causes. A total of 28 ESS fires occurred from 2017 to 2019. The continuous ESS fire accidents, which were highly expected to be a game-changer in the energy transition, became a social issue. The government conducted two official accidents investigations, but several limitations were revealed. Official investigations primarily focused on technical flaws, insufficient independence of the investigation committee due to the committee composition by the government initiative, and the reliability of the investigation results was questioned as the two investigations presented contradictory results on battery fire issues.

This dissertation tries to supplement the limitations of ESS fire accident investigation and analyzes in-depth the influence of factors such as social context on fire accidents. First, the process by which stakeholders adopt ESS technology is reviewed. In this process, social contexts such as politics, economy, and culture are explored for stakeholders and the impact of fires. Accordingly, qualitative data are collected through literature research and expert interviews, and the conclusion of this study is drawn through semantic network analysis and thematic analysis. Furthermore, it improves the causes of ESS fire accidents and redefines the development direction of ESS technology.

ESS technology, which can solve the intermittency issue of renewable energy generation, is becoming more critical. The government provided a strong policy drive for ESS by the provision of REC 5.0. The strong economic incentives provided to ESS elicited a response from the private sector and changed the social context. Various stakeholders interacted to accomplish their goals by utilizing

ESS technology. In this process, stakeholders faced conflicts and negotiated on the adoption of ESS technology as a technical artifact. ESS technology became a Black box as it was recognized as an unquestionable scientific fact, and ESS installations have increased rapidly. However, due to fire accidents, it was necessary to review the inside of the Black box (ESS technology).

In this study, the inside of the Black box is analyzed by applying the mixed method approach. First, Semantic Network Analysis was conducted based on interview transcripts. As a result, various issues such as communication problems among stakeholders and lack of risk perception were derived. Furthermore, based on the derived issues, Thematic Analysis was conducted. Various factors that can influence the occurrence of fires were identified in the social context and interaction of various stakeholders. In particular, the interactions of stakeholders generate adverse outcomes, such as structural problems, complex communication issues, disqualification of fire risks, and normalization of deviance. These interactions could lead to ESS fire accidents.

ESS fire case showed that ESS technology is socially constructed and is operating as a means for pursuing profit. Limitations in the utilization of ESS technology that stakeholders could not consider the internal risks of technology have been revealed. ESS technology was recognized as Black box without any questions or doubts, and several unexpected adverse outcomes were caused in the process of utilizing ESS by stakeholders. This dissertation has the significances of supplementing the limitations of the official accident investigation by examining the effects of social factors on fire accidents. In addition, this dissertation could provide a stepping stone for reconstructing the development direction of ESS technology, considering stakeholders' perceptions of ESS technology.

Contents

Chapter 1.

Introduction	1
1.1 Energy storage system and continuous fire accidents.....	1
1.2 Purpose of study	2

Chapter 2.

Theoretical background	5
2.1 ESS and fire risk.....	5
2.2 ESS related policy in energy transition.....	8
2.2.1 Governmental support policy of ESS.....	8
2.2.2 Safety regulation of ESS.....	10
2.3 ESS research trend and limitation.....	12
2.4 Social construction of technology and Usability.....	13
2.4.1 Social constriction of technology.....	13
2.4.2 Technology as Black box.....	15
2.4.3 Usability for technology improvement	17
2.5 Systemic approach for accident.....	18
2.5.1 Environment.....	20
2.5.2 Organization (structure and process)	23
2.5.3 Cognition/ choice	27
2.5.4 Cause of accident	28
2.6 Summary.....	30

Chapter 3

Method	34
3.1 Research Framework	34
3.2 Research design	39
3.3 Data collection	40
3.4 Analysis process	41

Chapter 4

ESS fire case and official investigation	43
-------------------------------------------------------	----

Chapter 5

Result	47
5.1 Black box: Socially constructed ESS technology.....	47
5.1.1 Social Environment: Changes in Renewable Energy Support Policy.....	47
5.1.2 ESS technology and social context.....	49
5.1.3 Relevant Social groups of ESS technology.....	50
5.1.4 Interactions of Social environment and Relevant Social Groups.....	52
5.1.5 Summary.	57
5.2 Exploring Significant issues on ESS fire accidents	58
5.2.1 Characteristics of ESS perceived by relevant social groups.....	60
5.2.2 Issues of ESS technology and fire causes by relevant social groups.....	64
5.2.3 Summary.....	70
5.3 Opening ESS fire accidents: Hidden fire causes in Black box.....	72
5.3.1 Environment.....	73
5.3.2 ESS organization (Structure & Process)	79
5.3.3 Cognition/ Choice.....	85
5.3.4 Theme development and summary.....	92

Chapter 6

Conclusion	96
6.1 Conclusion	96
6.2 Discussion	101
Reference	104

LIST OF FIGURES

2.1 Key component of B-ESS from Denholm (2019)	6
2.2 Relevant stakeholders of ESS industry modified from Hong (2017)	7
2.3 Process of battery fire from Feng et al. (2018)	8
2.4 The Socio-technical system involved in risk management from Rasmussen (1997)	22
2.5 STAMP Modelling from Leveson (2004)	23
2.6 Classification of risk with Interaction and Coupling from Perrow (1999)	25
2.7 Swiss cheese model of James Reason from Reason (2000)	27
2.8 Consist of modeling for PCS on ESS from Kim et al. (2019)	29
2.9 Work and Hazardous Process Chain of Events from Leveson (2004)	29
3.1 Research framework modified from Bijker et al. (1987), Bijker and Law (1994), Latour (1987, 1999), Perrow (1999), Pinch and Bijker (1984), Reason (2000), Vaughan (1996, 1999)	37
5.1 ESS Relevant Social Groups by author	51
5.2 Profitability simulation according to REC weight (5.0 vs. 3.5)	55
5.3 Semantic network result of Entire participant with Community analysis on ESS organization (Modularity 4.816, over 3.75)	62
5.4 Semantic network of Battery fields with Community analysis on ESS organization (Modularity 14.412, over 3.75)	67
5.5 Semantic network of EC with Community analysis on ESS organization (Modularity 8.026, over 3.75)	68
5.6 Semantic network of fire victims with Community analysis on ESS organization (Modularity 4.279, over 3.75)	69
5.7 Semantic network analysis result by RSGs	71
6.1 Analysis results of SNA & TA	100

LIST OF TABLES

2.1 Type of ESS from Hossain et al. (2020)	5
2.2 ESS safety regulation from Korea Fire Insurance Association (2019), ICC (2018), NFPA (2019)	10
2.3 Classification of approaches	31
3.1 Detail of Black box and cause of fire	38
3.2 Characteristics of Interviewees	40
4.1 ESS Fire accident official investigation results Modified from MOTIE (2019), MOTIE (2020)	43
4.2 ESS fire accident status Modified from MOTIE (2019), MOTIE (2020)	44
5.1 REC weights by energy source (2019) modified from RPS improvement plan (KEA, 2018)	48
5.2 ESS installation status from MOTIE (2019)	49
5.3 PV-linked ESS installation status modified from KEA (2018)	50
5.4 Condition of profitability of PV linked to ESS	54
5.5 Top 30 nodes of entire participant	60
5.6 Centrality of Entire participant	61
5.7 Top 10 nodes of each relevant social group	64
5.8 Centrality analysis of RSGs	66
5.9 Description of extracted codes	93
5.10 Detail of theme development	94

1. Introduction

1.1 Energy storage system and continuous fire accidents

Energy storage system (ESS) fire accidents have occurred in Korea and worldwide. For example, a 2 MWh ESS located in Arizona, USA, ignited and exploded on April 19, 2019 (Hering, 2019). However, there are no cases in which continuous fires occurred in an ESS, as in Korea. A total of 28 continuous fires (from August 2017 to June 2019) occurred in a battery-based energy storage system installed in Korea. ESS, expected to contribute significantly to energy transition in Korea, has become a social issue due to repeated fire accidents. The issue of fire accidents occurring in ESSs as a precursor to large-scale accidents has also been raised (Park, 2018).

ESS fires are difficult to extinguish owing to the chemical substances in the battery. Additionally, it is difficult to determine the cause of the fire as the incident scene is burned down. Accordingly, the Korean government formed an official investigation committee and conducted two investigations into the cause of the fires (MOTIE, 2019; MOTIE, 2020). In the first investigation, the government recruited ESS-related technical experts to form an investigation committee. Technical defects such as batteries, power conversion system (PCS), and battery management systems (BMS), which are the main components of ESS, the usage environment, and operation management were comprehensively analyzed. The first investigation committee concluded that the fires occurred due to a combination of defects in the internal protection system of the ESS and the operation and management environment. Five additional fires occurred during the first investigation period, and the second fire investigation was conducted. In the second investigation, the committee included technical experts and three additional parliamentary aides to supplement the objectivity of the investigation process. Contrary to the first investigation, the results of the second investigation concluded that the faulty battery was the direct cause of the fire (MOTIE, 2020).

However, the battery manufacturing industry conducted the same tests conducted by the investigation committee, presented its test results, and denied battery-related issues. Therefore, the cause of the fires continues to be debated (Kim, 2020c). Consequently, the current government fire investigation results and countermeasures did not reach a sufficient consensus among related ESS stakeholders. The government's official fire investigation has the following characteristics: First, the official investigation presents only the investigation results focusing on the technical flaws of the ESS (Kim, 2019a). The composition of the investigation committee was mostly centered on technical experts. The official investigation suggested the causes related to only the technical flaws but did not fully explain the influence of other factors such as social context. Second, the results of the first and second investigations showed results contradictory to the possibility that the main component of ESS, the battery, could be the cause of the fire (MOTIE, 2019; MOTIE, 2020). The results of the two surveys contradict the impact of the battery on the fire, casting doubt on the reliability of the results. Third, the

investigation committee lacked independence. The accident investigation committee should be independent of other investigating agencies in the process (Roed-Larsen and Stoop, 2012). However, the official investigation of ESS fires was conducted by an investigation committee organized under the government's leadership and not by an independent organization. This lack of independence may have made it difficult for the investigation committee to indicate the impact of the government's ESS-related policies or regulations on fire. For this reason, official investigations into the causes of ESS fires are limited as it is difficult for stakeholders to identify various factors, such as the social context that affected the accident during the development of ESS technology.

A fire investigation that does not comprehensively consider other factors, such as social context, creates difficulty in understanding the risks of ESSs. The limitations of fire investigations may cause a gap in understanding the public and ESS-related stakeholders on the relevance of other factors, possibly another cause of the fire. To prevent fire accidents and deter their causes, only improving technical defects and punishing those responsible is insufficient. The gap can be filled by understanding the impact of the social context that this failure has received in the technological development process. Accordingly, the ESS fire case needs to be recognized as a structural problem, and a comprehensive approach to the causes of the fire is necessary.

Technology does not develop rationally and efficiently but is influenced by social contexts such as related policies, stakeholders, interests, and external environments (Lee and Hong, 2006; Vaughan, 1999). Pinch and Bijker (1984) show that technology is socially constructed with "Relevant Social Groups" (RSG) and "Negotiation" according to their interests based on each group's "flexible interpretation." In ESSs, parts from various fields are integrated. Therefore, multiple RSGs have specialized knowledge and experience, leading to a different understanding of technology. Such differences can create conflicts of interest in the advancement of technology and can affect fires. It is necessary to examine the interaction between early RSGs and how the ESS technology was socially constructed to approach fire accidents.

1.2 Purpose of study

ESS-related studies deal with the concept and internal design of the system and the connection and use of renewable energy (Bhatia et al., 2006; Poullikkas, 2013; Zhang et al., 2018). Additionally, as ESS-related fires occur, an approach to mitigate fire risk is being developed. These studies mainly focus on the fire risk of batteries, fire-related regulations, securing the technical safety of internal control parts, and investigating technical defects (fire causes) for actual fire cases (Bubbico et al., 2018; Edison, 2017; Park et al., 2018; Rosewater and Williams, 2015).

Research on ESS fire accidents focuses on the inherent defects of the technology and suggests that improving technology can solve the fire risk of ESSs. These studies have a technologically deterministic

view and are considered essential such that the final form of technology is determined through the rational and efficient development of technologies. However, technical failures, such as ESS fire accidents, are an inevitable consequence of an efficient technology development process. Current ESS-related studies and the government's fire investigation results do not provide sufficient explanation for the development process of domestic ESS technology and the influence of social factors affecting the occurrence of fires.

The purpose of this dissertation is as follows. First, this study examines how ESS technology has been adopted (consensus among members) and utilized by relevant social groups (stakeholders). Therefore, it is necessary to approach the ESS fire accidents from the standpoint of "social construction of technology" rather than simply technical failure.

Second, this study explores the processes and interactions between RSGs and the risk factors of ESS technology. It attempts to explore the relationship between the influence of stakeholder(s), the social context, and fire accidents in the social construction of ESS technology. Risk can be defined through the cultural, academic, and institutional factors that constitute a social context (Douglas and Wildavsky, 1983; Jasanoff, 1986; Slovic et al., 1982). Various social groups can create technological risk factors in a social context. In interactions through their expertise, interpretation, and interest in technology, risk factor(s) gradually accumulate and eventually result in unexpected adverse outcomes (Vaughan, 1999; Aini and Fakhru-Razi, 2010). Therefore, it may be biased to view the causes of ESS fire accidents as sudden technical defects. Instead, it is necessary to explore the relationship between the mutual influence of RSGs and the surrounding social environment to define and analyze the risk factors of the technology properly.

Finally, this study suggests the direction of future technology development, rather than merely exploring the fires caused by the socially constructed ESS. A comprehensive examination of the causal relationship between technological failure and the social context of ESSs in the era of energy transition means identifying the technology development process, risk factors, new technology acceptance, and reduction of potential problems in energy transition processes. Such an attempt is meaningful in that it can provide a better direction for the development of technology. The research questions were as follows:

- 1) Are ESS fire accidents simply a "failure" of technology? Or are they a "socially constructed" technical problem?
- 2) What is the meaning of continuous fire accidents in the process of socially constructing ESS technology? What is the causal relationship between the relevant social group(s) perception, interpretation, and negotiation of technology and fire risk?

- 3) The fire risk of ESS was constructed through the “relevant social group (RSG)” and “environment.” How should the risks of socially constructed ESS be improved?

2. Theoretical background

2.1. ESS and fire risk

ESS is a technology that can store the electricity produced and supply it when needed. Energy storage systems can be classified according to the type of energy storage. Traditionally, the most used energy storage method was pumped hydropower generation, but recently, the ESS industry of chemical storage method using lithium-ion batteries has greatly expanded.

Table 2.1 Type of ESS from Hossain et al. (2020)

Type		ESS	Characteristic
Battery	Electromagnetic	Super capacitor	-Direct charging of electricity by electromagnetic method. -High charging/discharging efficiency, high output
	Electrochemical	Secondary battery	- High power, high energy density, fast response - Easy to scale-up, applicable to a wide range - Various battery types (LiB, NaS, Lead acid, RFB, Etc.)
Non-battery	Mechanical	Flywheel	- Storing rotating kinetic energy as electrical energy - Relatively short discharge period compared to high power
		Pumped Hydro Storage	- Low operating costs - Energy storage up to GW level - Installation equipment is limited

Recently, electrochemical ESS is rapidly expanding. This electrochemical ESS mainly refers to the use of secondary batteries. Battery ESS(B-ESS) is composed of four main parts: battery, BMS, PCS, and EMS (Energy Management System). The use of lithium-ion batteries as secondary batteries for ESS is increasing. BMS is a battery management system that controls the state of the battery. BMS includes various diagnostic functions such as battery monitoring, protection, and cell balancing. PCS is a Power Conversion System that plays the role of charging and discharging the electricity of the battery. In particular, PCS refers to a device that converts electrical characteristics (AC/DC) for receiving power from a power source inside the ESS equipment and storing or discharging it in a battery. PMS is a Power Management System that monitors and controls the status of batteries and PCS and means an operating system for monitoring and controlling the entire ESS facility in a control center (Hong, 2017).

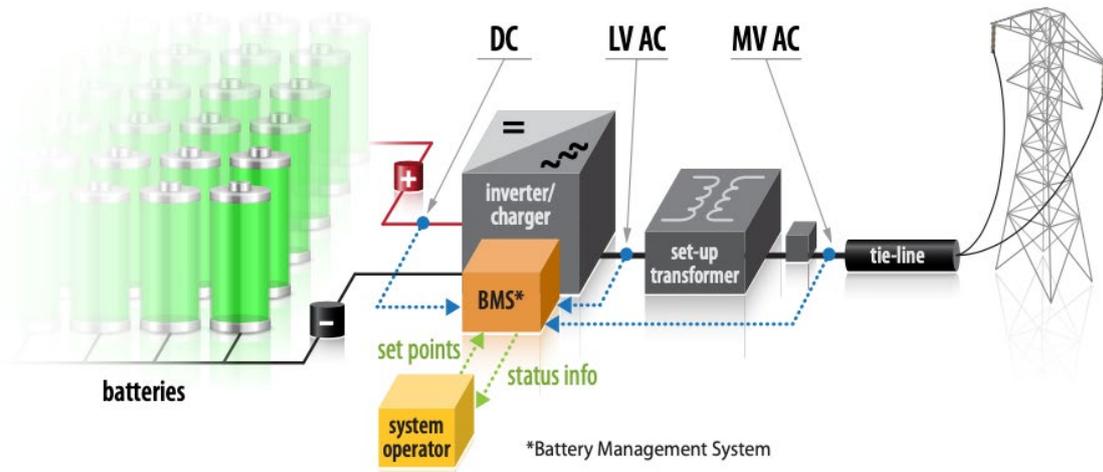


Figure 2.1 Key component of B-ESS from Denholm (2019)

According to Hong (2017), there are developers and EPC (Engineering, Procurement and Construction) companies planning and installing ESS installation projects in addition to the power storage part (battery) that composes the primary ESS system and the power converting part (PCS) that manages power transmission, distribution, and charging are doing. The overall ESS industry composition can be primarily composed of a part that composes hardware and operates the system.

When ESS stakeholders are classified, they can be divided into ESS configuration and utilization parts. The configuration part that can be divided into battery manufacturing and the control part that stores and supplies electricity by using it. There are EPC companies that assemble the main systems of the configured ESS. Most of the EPC work is handled by the PCS company (Hong, 2017). ESS utilization part can be divided into government and users. The government provides policy support to ESS to promote the spread of RE. So, users install ESS to pursue economic benefits. Users are largely composed of manufacturing plants that receive discounts on electricity rates and private RE electricity generation operators when they sell electricity for additional revenue. The following figure 2.2 is the stakeholder groups related to ESS.

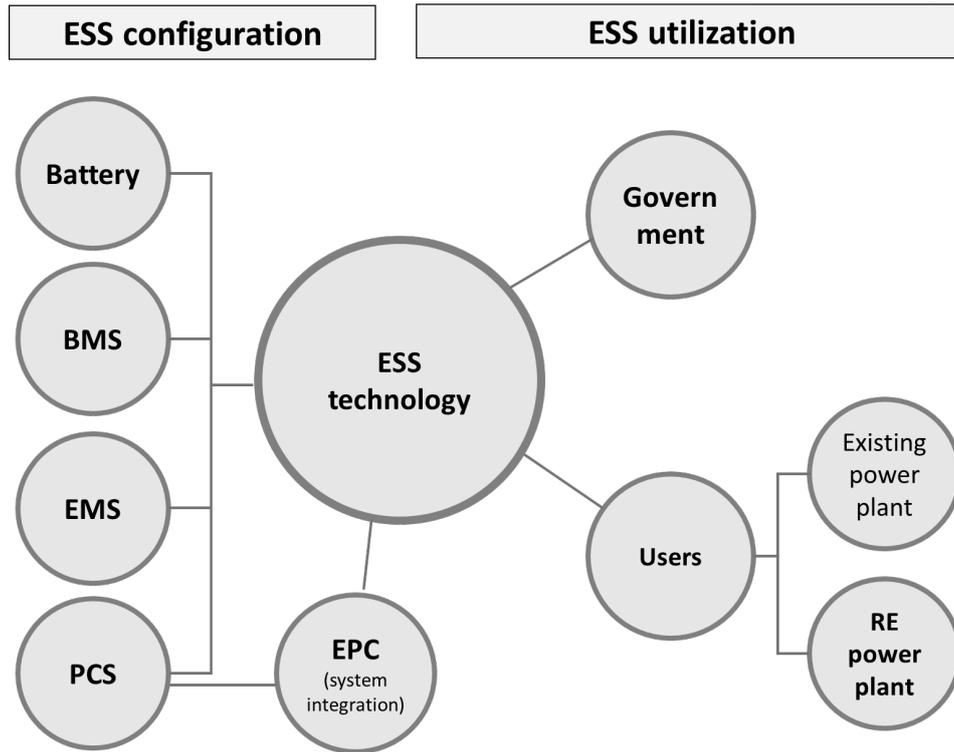


Figure 2.2 Relevant stakeholders of ESS industry modified from Hong (2017)

1) Fire risk of B-ESS

Lithium-ion rechargeable batteries already represent an energy storage technology commonly used in many applications (cell phones, laptops, Etc.) and will play a more critical role in the future. Most of the currently installed ESS use lithium-ion batteries, and all ESS with fire accidents use lithium-ion batteries (Noh, 2019). Lithium-ion batteries' risk issues include manufacturer defects, over-charging/ discharging, internal short circuit, and thermal runaway (Liao et al., 2019).

The temperature of Lithium-ion batteries may rise due to the movement of lithium ions and electrochemical reactions during charging and discharging, and under normal operating conditions, the performance and safety of the battery are not adversely affected. Battery ESS installs battery packs in which numerous cells are gathered to store electric energy. At this time, if the battery is abused or proper temperature control is not performed, the cell may collapse and thermal runaway may occur (Edison, 2017).

Thermal runaway refers to a rapid increase in temperature due to the self-heating of a battery cell. Thermal runaway is the most dangerous factor in battery fires. The mechanisms by which thermal runaway occurs are as follows. A battery is composed of cells, and a separator separates each cell. However, if the separator is damaged due to an external shock or overvoltage, the electric energy that has been charged is rapidly released to the outside as the anode and cathode of the cell contact. The off-gas is generated at this time, which further damages the adjacent cell's separator. This mechanism is

repeated continuously within a short period, and gas and electrolyte leak out of the battery container and lead to ignition, called thermal runaway. The following figure describes the process of a battery fire caused by the abuse of the battery (physical shock, excessive charging and discharging, overheating).

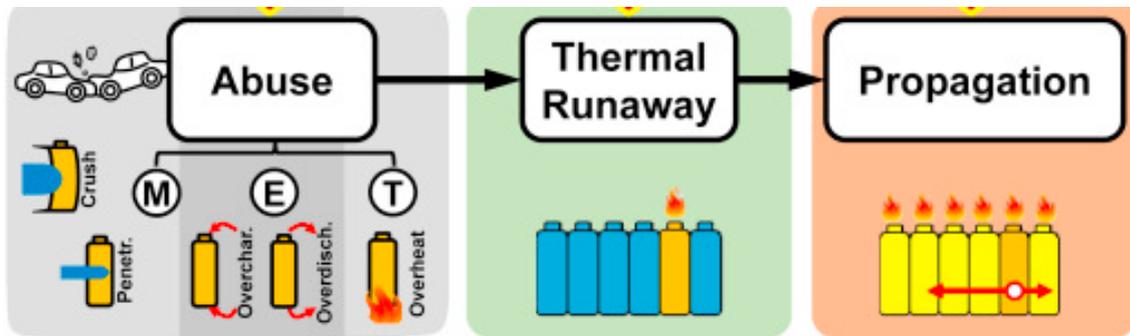


Figure 2.3 Process of battery fire from Feng et al. (2018)

Abusing battery ESS that overcharges or over-discharges can cause heat to accumulate and increase in temperature due to the chemical reaction between the anode and separator inside the lithium-ion cell (Wang et al., 2019). When the temperature increase inside the cell is greater than that of external heat dissipation, the temperature inside the cell is continuously increased. The separator inside the cell collapses at the critical temperature. This cell breakdown can lead to thermal runaway of the battery (Bubbico et al., 2018).

2.2 ESS related policy in energy transition

In the era of energy transition, government utilizes various support policies and regulations to expand RE. When the government sets support policies, it considers all costs and benefits and sets policies to increase social benefits (Felder, 2016). RE has a higher generation cost compared to other fossil fuels in the energy system. This cost is due to the high initial installation cost of renewable energy generation equipment and make difficult to invest by private sector. Since the country has limitations in time and capital to directly install all facilities such as ESS, private capital participation is required, and for this, the government needs a support policy through subsidies or incentives (Lee, 2014).

2.2.1 Governmental support policy of ESS

To reduce the power grid load and overcome the intermittency of renewable energy, the role of the battery-based energy storage system (after this ESS) is essential (Kear et al., 2012). Accordingly, Korea government is supporting energy policy using the FIT system that provides government subsidies and the RPS (Renewable Energy Portfolio) system that provides incentives to private business sector such as, small renewable energy power generator (Kwon, 2018). Along with this, as the importance of ESS

grows, the government provides various policy support to expand ESS through RPS. For example, the government provides incentives for the sale price of electricity produced by the RE power plant when it is linked to the ESS (KEA, 2018).

Governmental support policies for encouraging ESS installation are mainly divided into two categories. First, it provides financial support (subsidies, tax cuts) for the initial market formation. Second. In some cases, policy support (such as specifying the ratio of distribution mandatory) is also used (Lee, 2014). Countries around the world are expanding ESS-related facilities through these support policies.

According to Kim (2018b), the U.S. introduced the world's first mandatory installation of ESS and promoted support policies such as tax reduction and discriminatory rate system at the federal level. At the state level, market formation policies were also promoted through tax reductions and subsidies to encourage investment. In September 2010, California enacted an ESS installation mandate. Besides, it is actively introducing support policies such as tax benefits and differentiated rates. In addition to California, Massachusetts and Oregon have introduced these mandatory systems. In Germany, subsidies are provided mainly for household ESS in connection with renewable energy. When the ESS is installed, the electricity grid connection fee is also exempted. As a representative means of financial support, subsidies have been provided up to 30% of the cost of installing solar power or photovoltaic (PV)s related ESS since 2013. 'Kfw program 275' provides low-interest loans to consumers and supports home and commercial subsidies. The privatization of the electricity market was encouraged using these policies. As a result, private power generation projects can enter the market freely. The proliferation of energy prosumers was easy as private utility companies set their prices. In Japan's case, after the 2011 earthquake, the government actively supported the installation of residential ESS, especially in preparation for an emergency outage. ESS for home use is dominated by roof solar power. The Japanese government has supported up to one-third of the installing ESS cost for 12 years from 2011 to solve the shortage of electricity and foster the lithium-ion battery industry.

In Korea's case, ESS can be an effective means to establish a stable and efficient energy supply and demand system. In other words, the enormous market potential was expected and attracted attention as a new growth engine. Since the pilot project started in 2009, it has been mainly used for power frequency adjustment. Subsequently, as policy support was strengthened in 2016~2017, ESS operation revenue increased and facility installation cost also fell, and the supply volume increased rapidly. In Korea, ESS begins to increase rapidly from 2018. According to Kim (2018a), The government provided REC weights of 4.5 to 5.0 for ESS linked to renewable energy generation that guarantees private power generation operators' profit. Unlike the existing RE power generation, where the REC weight was paid from 0.5 (waste-utilized power generation) to 1.2 (photovoltaics) depending on the type of power generation source (KEA, 2018), additional electricity sales revenue could rapidly increase. Through this, the supply of PV and wind connected ESS has increased dramatically. In the end, Korea, like

overseas, implemented various support policies to achieve the goal of expanding RE. In response, the private sector responded by installing ESS to obtain additional profits.

2.2.2 Safety regulation of ESS

There are standards for regulations to ensure the safety of ESS in Korea. Safety standards related to energy storage devices are still in the early stages of development. Globally, ESS-related safety standards are set and applied by organizations such as NFPA, International Code Council, UL and IEC. Meanwhile, after the several ESS fire accidents, Korea is newly introducing ESS installation standards as safety measures, enacting ESS-related Korean Industrial Standards (KS), and introducing ESS components KC (Korea Certification) (Noh, 2019).

Existing official ESS-related safety regulations are 'Inspection guidelines for energy storage system (SPS-KESG-VI-M-14-7286)' of Korea Electrical Safety Corporation, which is an ESS inspection standard, and 'Criteria for Electrical Equipment Technical Standards' of Korea Electric Association, which is an ESS electrical safety standard. However, there are no standards on ESS installation, maintenance, and thermal runaway tests covered in overseas ESS-related safety regulations. Furthermore, domestic ESS safety regulations are limited to the level of comprehensive description. On the contrary, overseas safety regulations set and apply specific standards and contents in detail, from the type and usage of fire extinguishing equipment related to ESS fires to major safety management items such as thermal runaway. For example, regarding the fire extinguishing equipment installed inside the ESS, the NFPA describes explicitly the amount of water sprayed for fire extinguishing, the fire hydrant location, and a fire extinguishing facility capable of spraying water into the battery storage room (ICC, 2018; NFPA, 2020). The ESS safety regulations are as follows.

Table 2.2 ESS safety regulation from Noh (2019) NFPA (2020) ICC (2018)

Organization	Title	Year	Content
International Code Council	IFC Section 1206, Electrical Energy Storage Systems	2018	ESS installation and Maintenance
National Fire Protection Association	NFPA 855, Standard for the Installation of Stationary Energy Storage Systems	2020	ESS installation and Maintenance
Factory Mutual Global	FMDS 0533, Electrical Energy Storage Systems	2017	ESS installation and Maintenance
International Electrotechnical	IEC 62933 – 5-2, Electrical Energy	2017	Electrical safety standards of ESS

Commission	Storage (ESS) systems Part 5-2: Safety requirements for grid-integrated EES systems – Electrochemical based systems		
Korea Electrical Safety Corporation	SPS-KESG-VI-M-14-7286, Inspection guidelines for energy storage system	2018	Inspection standard of ESS
Korea Electric Association	Criteria for Electrical Equipment Technical Standards (295 ~ 297)	2019	Electrical safety standards of ESS
Underwriters Laboratories	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems	2018	Thermal runaway standard of ESS

In the ESS internal circuit, constant electrical interaction between the electric and electronic control parts and the battery occurs. Accordingly, the ESS must constantly monitor the charging/discharging status of the battery, control all devices such as power conversion devices, and always monitor abnormal conditions. For example, IFC 1206 regulations monitor battery voltage, current, and temperature and require alarm signals to be transmitted when dangerous temperatures, short circuits, over-voltages, or under voltages occur. Also, in the IEC 62933-5-2 standard, all parameters deemed important to the system status, such as voltage, current, temperature, and state of charge should be measured, monitored, and recorded. Since there is a possibility of thermal runaway of the battery even after the system is disconnected, remote monitoring is continued even after disconnection.

Currently, the domestic ESS inspection guidelines require monitoring for ESS facilities of 1MW or more. The measuring device is prescribed to monitor voltage, current, power and charge/discharge status. PMS and BMS require measurement, control, protection, communication, and storage functions. However, there are no specific operating conditions for monitoring functions such as accurate monitoring frequency (Noh, 2019).

There are many other things to consider for safety. For example, there are smoke and fire detection, regulations related to the ESS installation location, environmental factors (temperature, humidity, vibration, waterproofing, moisture-proof), protection zone setting, ventilation equipment, and earthquake resistance regulations. In addition, there are many other things to consider for safety. For example, there are smoke and fire detection, regulations related to the ESS installation location, environmental factors (temperature, humidity, vibration, waterproofing, moisture-proof), protection zone setting, ventilation equipment, and earthquake resistance regulations. However, the domestic ESS industry is in the early stages of market formation and growth, and safety is an essential regulatory

factor, but many aspects have not been properly considered. In particular, in this situation, the ESS industry has not secured safety correctly due to the rapid spread of ESS linked to PV.

However, before the ESS fire, there were only safety-related private sector standards for ESS products. There was no official KC (Korean Certification) as compulsory authentication. As a private-sector standard, the 'General performance requirements of PCS (Power Conversion System) for electrical energy storage system (SGSF-025-4-1972)' of the Korea Smart Grid Association was first established in 2012. Korea Battery Industry Association established a 'Secondary lithium-ion battery system for battery energy storage systems — performance and safety requirements (SPS-C KBIA-10104-03-7312)' was registered in 2018. However, the chronic problem of these private-sector standards is the completeness and quality of the standards. In terms of the completeness and quality of domestic private sector standards, it is pointed out that development and verification capabilities are relatively lacking compared to overseas organizations (Choi, 2013). The situation of ESS-related private sector standards is quite similar. Domestic private sector standards have a limitation in that they only present the necessity of securing safety at a general level rather than suggesting specific safety standards presented by safety standards of other countries.

2.3 ESS research trend and limitation

Trends in ESS-related researches can be divided into two categories. Early ESS-related researches mainly deal with the concept and internal design of the system and its link to and utilization of renewable energy (Bhatia et al., 2006; Poullikkas, 2013; Zhang et al., 2018). Battery-based energy storage systems perform electric power control functions such as load leveling/peak saving of the grid and can provide solutions to many operational problems faced by power systems (Bhatia et al., 2006). They show the simulation of the operation and efficiency of various control parts such as the PCS inside the B-ESS. Poullikkas (2013) analyzed the economic feasibility of various types of batteries and the advantages and disadvantages of ESS as a power application. Zhang et al. (2018) pointed out the introduction of ESS linking with renewable energy and the need for high-performance, large-scale battery storage systems. He also mentioned the importance of internal protection systems, such as PCS, to protect high-performance batteries from shocks that occur during charging and discharging.

As a fire occurs in the battery energy storage system, researches on the fire risk of battery ESS are also in progress. The ESS studies are mainly concerned with battery fire risk, fire-related regulations, securing technical safety of internal control parts, and investigating technical defects (causes) of actual fire cases (Bubbico et al., 2018; Edison, 2017; Park et al., 2018; Rosewater and Williams, 2015). As the development and internal structure of ESS become more complex, scenario-based risk assessment considering the fire characteristics of lithium-ion batteries is conducted, and ESS internal system design is focused on securing safety (Rosewater and Williams, 2015). There are also studies on fires for ESSs

based on lithium-ion batteries. Bubbico et al. (2018) established major fire risk scenarios in lithium-ion battery-based ESS and suggested mitigation measures. The scenario is based on possible adverse interactions between the battery system and the surrounding environment (power system, installation location and usage). In addition, there are the results of fire-extinguishing tests and fire extinguisher testing programs for various lithium-ion batteries, lead-acid, and Vanadium Redox batteries used in ESS (Edison, 2017).

ESS has spread rapidly with the increase in the use of renewable energy as well as traditional functions such as load control of the power grid. Accordingly, as fire accidents occur, research on the risk is in progress, but accident approaches focusing on technical causes are predominant. However, it does not provide a sufficient explanation for the influence of the user(s) and social contexts on ESS fire accidents. The development of ESS has been influenced by energy transition trends and energy-related policies and regulations. Therefore, the approach to fire risk requires consideration of not only technology but also social contexts as well.

2.4. Social construction of technology, Black box and Usability

Science and technology studies (STS) explores the contribution of science and technology knowledge to the development of knowledge and social change through various perspectives such as philosophy, sociology, and history (Sismondo, 2011). In STS, the scope of research was expanded and elaborated not only on science and technology knowledge, but also on technical artifacts, methods, phenomena, institutions, interests, history, and culture.

STS assumes that science and technology are social, active, and artificially created from the perspective of constructivism, rather than the essentialist that science and technology exist by themselves (Sismondo, 2011; Hacking and Hacking, 1999). In other words, science and technology do not exist naturally as the technology itself but are created through interaction with surrounding environmental factors such as policies, institutions, actors, and interests (Sismondo, 2011). Due to these characteristics, science and technology are socially adopted through social conflicts and compromises arising from actors' interests (Bijker et al., 1987; Song, 1999; Sismondo, 2011). After all, technology does not have only one efficient development trajectory. Still, among several possible development trajectories, a specific type of technology is selected and utilized by actors' interests related to science and technology (Song, 1999).

2.4.1. Social construction of technology

Among the representative theories that explain the relationship of social influence on science and technology, the “Social Construction of Technology (SCOT)” is reviewed in this part. Representative

theories that explain the relationship between technology and society are "technological determinism" and "SCOT," which emerged while criticizing it (Sismondo, 2011; Lee and Hong, 2006). The two theories differ in their fundamental assumptions about science and technology. Technological determinism points out that science and technology itself pursues efficiency through the same path regardless of time and space, that is, the unique development logic of science and technology itself, and that influence of specific science and technology affects social change equally in any society (Lee and Hong, 2006). However, technological determinism does not consider the influence of society on technology, such as humans, politics, education, and culture that change technology. Therefore, there is a limit to explaining the relationship between technology and social change (MacKenzie and Wajcman, 1999; Song, 1999). MacKenzie and Wajcman (1999), citing the development process of computer technology as an example, criticized the limitations of technological determinism, pointing out that the designers of technology contained their values in technological development was reflected in the change of technology.

SCOT is the view that technological artifacts are socially constructed by extending the social constructionist perspective that originated from STS to the realm of technology. SCOT criticizes 'essentialism' that the trajectory of technology development is already determined within technology and emphasizes the influence of social groups that adopt and utilize technology on technology (Lee and Hong, 2006). Bijker et al. (1987) point out that various social groups interact through flexible interpretations of technology and that technological artifact is socially constructed. They pointed out that RSGs adopt technical artifacts with their own interests through conflict and negotiation. Bijker et al. (1987), when defining the relevant social group (RSG)s, assume that they have a specific identity on technology. Furthermore, the identity is based on the shared meaning of members within the groups. In the end, this shared meaning is influenced by socio-cultural and political contexts and forms the specific meaning unique to the social groups that members share with certain technological artifacts. In particular, the RSGs included not only specific organizations such as corporations but also groups of unorganized individuals.

Conflict arises from the interpretations that social groups grant to artifacts and the differences between these interpretations. The resolution of these conflicts is influenced by the strength and size of the social group (Bijker et al., 1987). RSGs on technology are interest groups based on pursuing their own profits. Therefore, in the process of technological change, each RSG has a different interest in the problem of the same technology and proposes a different solution (Bijker, 1997). Differences in interpretation among RSGs based on these interests lead to conflicts over the final form of technological change. Conflict occurs because the problem recognition and solutions for a specific technology are different among groups, and the final form of technology is adopted through a negotiation process that narrows differences in the interests of each other (Lee and Hong, 2006). For example, there is a case in which technology related to bicycles is socially constructed. In the early days, bicycles had various

forms depending on the group's awareness of problems and solutions to technology. There were various asymmetric wheels, materials, and frame shapes. However, each social group using the bicycle negotiated to incorporate the different forms, resulting in bicycles using the diamond-shaped frame and rubber wheels that are mainly used today (Bijker, 1997).

Negotiation is essential to resolve conflicts between relevant social groups over technology. Negotiations involve the interests of relevant social groups, and thus an agreement is reached through a very complex and multidimensional process. Therefore, the negotiation of groups has a collective, political, and cultural character rather than an individual one (Lee and Hong, 2006). SCOT describes the final adoption of a specific technology through interactions such as conflict and negotiation with RSGs, groups' interests and the technical artifacts have the impacts that change society and individual experiences (Sismondo, 2011).

However, SCOT has the following limitations and criticism. First, it focuses only on the emergence of technology itself and is indifferent to the impact of technology on social structure and individual experiences. In other words, after relevant social groups adopted the technology, there is a criticism that it does not discuss personal experiences or social changes due to technology. Accordingly, Kline and Pinch (1996) analyzed the impact of automobile technology on rural areas in the United States and discussed not only the emergence and social choices of technology but also the impact of technology on individual experiences and society. Second, the researcher's arbitrary interpretation of the process in which the products of science and technology are constructed may occur (Clayton, 2002). Because arbitrary conceptualizations may be problematic depending on the researcher's perspective, SCOT may not provide a clear and sufficient explanation of the mechanisms of occurrence and closure of interactions (conflicts and negotiations) among RSGs. Lastly, SCOT does not deal with changes of social structure or power relation due to the technical artifact. In other words, there is criticism that SCOT are not interested in the political issues surrounding technology and are indifferent to the impact of technology on social change (Lee and Hong, 2006). Therefore, SCOT is indifferent to the impact of changes in technology on individuals and society and does not provide sufficient discussion on the future direction of technology development.

Interestingly, although conflicts among relevant social groups play an important role in the construction of technology, there is no clear explanation for this limitation. As mentioned above, conflicts and negotiations among the social groups are very complex and multidimensional. However, if the process of occurrence and termination of these interactions is not properly reviewed, it may act as a limit to improving the problems of the technology and setting the direction for future development. Therefore, it is necessary to explore the processes and consequences of interactions.

2.4.2. Technology as Black box

To approach the conflicts of social groups, the abstract concept of the engineering term “Black box” is utilized (Sismondo, 2011). Conventionally, Black box is an engineering term that refers to a machine that outputs an appropriate result according to a certain input (Latour, 1987). The term is an abstract concept that only discusses the relationship between input and output rather than focusing on the internal complexity of the machine. STS utilizes this concept of a Black box to describe the process by which scientific knowledge is adopted through controversies among social groups (Sismondo, 2011). Scientific knowledge is constructed not only by scientific facts but also by various assertions that support it. Through this process, conflicts and controversies related to technical artifacts are closed, and they become a scientific fact that no one doubts and utilized broadly.

When a technical artifact, the final product of scientific knowledge, operates efficiently or is stabilized, relevant social groups and members do not pay attention to the internal complexity of the product, and this technology is said to be Black box (Latour, 1999). Latour (1987) pointed out the process by which technical artifacts are socially constructed and stabilized as follows. Scientific knowledge is adopted by society through strategic actions by scientists in social construction. These interactions decide the final form of technical artifact that translated from scientific knowledge (Sismondo, 2011). The scientific knowledge created in this way is called “Ready-made science” and is called Black box, whose contents are now very solid and certain, and treated as a scientific fact without further doubt by those who accept the technology (Callon and Latour, 1981; Latour, 1987).

Black box is formed by the interaction of several related social groups as seen in SCOT. In the adoption process of “technical artifact”, each social group acquires peers (human or non-human) to support it according to their interests and adopts the technology collectively. In this case, the "technical artifact" becomes a dominant "scientific fact" that is adopted without doubt or question by other "scientific knowledge" and "technologies (or machines)". In this way, the "scientific fact" is strengthened by backing up another "scientific fact" or "technology". The dominant "scientific fact" is more widely used by RSGs. This “technical artifact” becomes a Black box and acts as a kind of mean used to achieve the purpose of each RSGs (Sismondo, 2011; Latour, 1987).

In this way, Black box leaves only the inputs and outputs for the user's specific purpose accomplishment rather than focusing on any historical facts, controversies, and complexity within it. And these Black-boxed technical artifacts blur the interaction between users and socially constructed technical artifacts (Besel, 2011). In other words, the technology as Black box makes the relationship between the artifact and the social group(s) using it opaque and ambiguous. However, 'Black box' has the potential to be open and reexamine due to the influence of a specific situation or event.

Beck (2008) points out that the main concepts of STS can be applied to understanding disasters caused by the impact of technology. For example, if the cooling system of the Chernobyl nuclear power plant had worked properly, it would not have been a disaster, and the public would have been unaware of the dangers of the nuclear plant after all. In other words, nuclear technology was a kind of 'Black

box' for some relevant social groups who used the technology until before the disaster, who undoubtedly adopted and utilized the technology. However, when the disaster occurred, a 'Black box' could be opened, which led to a discussion of technical artifacts and an internal review of the entire technical system. Through this process, "Ready-made science" is transformed into the state of "science in action", and social groups search for its internal structure (Latour, 1987). After the Fukushima nuclear accident, Korea became aware of the risk of nuclear power again. It reached a social consensus to reduce nuclear power in the process of energy transition gradually (Chung, 2020).

After all, disasters have opened a 'Black box', and it is important to examine the conflicts and negotiations of relevant social groups involved in reexamining in the box. It is necessary to review the process of generating adverse outcomes and the effects that these interactions can have. Bijker and Law (1994) referred to the future of SCOT as the need for constructive science and technology to contribute to a better society. Technological failures, such as nuclear disasters, modify the direction of technological development.

2.4.3. Usability for technology improvement

Usability refers to a qualitative attribute that evaluates how easily a user can use a technical interface. Norman (2013) pointed out that technological interfaces between technology and human interaction for usability should be functional, easy to use, and intuitive. In other words, users should be able to use the technology conveniently and efficiently without having to understand or learn everything about the technology.

This usability has the following five qualitative attributes (Nielsen, 2012). The five qualitative components that define usability are learnability, efficient, memorability, errors and satisfaction, and the usability of technology is improved based on these concepts. Norman (2013) suggested the principle of system design by utilizing this 'usability'. In particular, he presented the characteristics of visibility, feedback, affordances, mappings, constraints, and consistency in the 'usability' design principle for human-technology interaction (Norman, 2013; Nielsen, 2012).

The meanings of the conceptual elements suggested in the usability design principle are as follows. First, Visibility should be something that anyone can intuitively understand when they come into contact with technology. Second, Feedback requires each response to all actions of the user, and through this, it is possible to understand the interaction between humans and technology. Third, Affordance means that users can easily understand how to use the technology by providing a prompt that helps them to understand the technology easily and through these clues and interactions. Fourth, Mapping means that when a user controls (or operates) a specific element, it is possible to properly understand where the effect is occurred due to the relationship between control and effect within the system. Fifth, Constraint induces an efficient choice and naturally leads to the next action by limiting the scope of the

user's action with the intended limit of the set of actions that the user can use. Finally, Consistency means that a specific reaction to technology must have the same reaction, which can prevent confusion in the use of the technology.

These qualitative concepts of 'usability' provide an opportunity to grapple with the direction the interaction between users and technology should take in technological change. For example, Feedback on a specific action provides immediate reaction on the user's action selection, and the user can identify potential danger signals in advance. These conceptual elements discussed above are meaningful in that they can remove or manage the causes of accidents in advance based on an understanding of technology and mitigate the damage even when accidents occur.

'Usability' is already being utilized in the aspect of usability engineering that attempts to control risks. Van Der Peijl et al. (2012) analyzed medical device accident cases and pointed out that medical devices used every day have repetitive usage patterns. Moreover, they pointed out that accident prevention needs to apply 'design for risk control' in consideration of repeated use patterns.

After the Black box is reopened due to an accident or disaster, the direction of development of new technology needs to consider when the Black box is closed again. The resealed Black box is undoubtedly used by various social groups that utilize the technology, leaving no doubt about the risks inside Black box such as, internal complexity. Therefore, when resealing the Black box, a design that can control risks can play an important role in reestablishing the direction of technology development.

2.5. Systematic approach for accident

In perspective of SCOT, various social factors affecting the final adoption of technology could be found. When certain events occur, such as technical failures, the undoubtedly used technology - Black box - is reopened and reexamined. In particular, it is necessary to explore the interactions of various RSGs that construct technology socially and find out what caused the failure. However, SCOT only points out the complexity of the interaction, and there are problems of the researcher's arbitrary interpretation and insufficient explanation of the interactions among social groups.

A clue on the interactions of these social groups can be found in 'Social Shaping of Technology'. Social shaping of Technology is one of the discussions that approach scientific knowledge based on structural relationships such as power and class in STS. For example, power relations among social groups are based on the interests of each group, and these structural power relations can limit the specific direction and content of technological development (MacKenzie and Wajcman, 1999). Social groups using technology form a kind of structural relationship that connects and interacts with other groups, and some actions of certain groups can be limited or influenced by their relationships with other groups (Williams and Edge, 1996). Therefore, the structural relationship of groups in social formation

theory can be a start point to the discussion about the process of interaction and technological artifacts that SCOT could not present.

In the case of ESS fire accidents, despite the continuous fire, it was difficult to determine the cause of the fire properly, and the official fire investigation report presented results focusing on technical causes. Therefore, to properly identify the causes of fire accidents and improve ESS technology, a comprehensive approach is required with various social factors that have influences on continuous fires. From the point of SCOT view, it is necessary to consider the effects of various social groups and environments that occur in the process of socially constructing the ESS technology. It is necessary to explore the interactions within Black box, from interpretation on ESS to conflicts and negotiation with various relevant social groups and technologies. Various accident approach models consider the relationship between accidents and social factors by utilizing concepts to explain the causes of accidents. Therefore, the inside of the Black box is reexamined using the main concepts used by various accident approach models.

The government's official accident investigation focuses on solving problems by improving and identifying direct technical deficiencies to fire accidents (MOTIE, 2019; MOTIE, 2020). Concentrating only on direct causes may not consider other factors that may influence the generation of these causes. The focus of approaches to accidents and disasters has shifted from addressing direct and quantitative risk criteria to addressing systemic deficiencies and considering the social context (Stoop, 2004). The approach to the causes of accidents or disasters considers not only the individual level but also the interactions inside and outside the organization(s), influence relationships and external social contexts (Vaughan, 1999; Perrow, 1999; Hall, 1996).

Many accidents are continuously occurring, and various accident approach models have been developed and used to analyze the causes of accidents (Leveson, 2004; Leveson, 2011; Perrow, 1999; Rasmussen, 1997; Reason, 2000). There were various approaches to the cause of accidents, in the early stage of accident investigation, the approach that viewed the hardware or equipment failure itself as the cause of the accident became mainstream. Since then, accidents, and disasters caused by people's mistakes such as 'Human error' have been considered, and this model still occupies a stable position as an accident approach model (Dallat et al., 2019).

Accident approach models that from a social constructivist perspective began to be mainly used in the late 1970s. These models are examining the impact of social factors leading to technology failure to approach accidents. Social constructivism offers three important assumptions, or perhaps a reminder: 1) Science and technology are social, 2) form a structure, and 3) science and technology appear as products of artificial science and technology rather than a direct connection from natural phenomena to ideas (Sismondo, 2011). Accordingly, the external background where the accident occurred, society was recognized as a system, and the relationship between the internal and external components, that is, society, the organization and the members, was analyzed (Rasmussen, 1997). At present, accident is

now widely recognized as a systemic phenomenon and is currently becoming mainstream in accident analysis research (Dallat et al., 2019; Underwood and Waterson, 2014).

Beck et al. (1992) pointed out that the risk factor of modern science and technology civilization in the risk society' differs qualitatively from traditional society. Disaster can be caused by various social factors such as society, economy, culture, and politics (Vaughan, 1999; Vaughan, 1996). Suboptimal outcomes like an accident or disaster interact with socially organized settings such as organizations, politics, economy, culture, and technology and systematically produce organizational deviance that is a routine by-product of the system's routine nonconformity (Vaughan, 1999). Therefore, various accident approach models are reviewed using conceptual factors such as environment, organization, and cognition/choice (Vaughan, 1999) that influence accidents.

2.5.1 Environment

Environment is complex, aggressive, changing, turbulent, and can impact the organization (Hall, 1996). Due to these characteristics, the environment has uncertainty, which can lead to unintended consequences. This uncertainty makes it difficult to predict specific situations that may affect future consequences accurately. The environment can have the best, sub-optimal, or adverse outcomes for an organization's activities (Vaughan, 1999). Moreover, even if the environment is properly set up, sub-optimal results may come out instead of the expected best results (Pressman and Wildavsky, 1973; Wilson et al., 1996).

Environmental factors that influence the occurrence of unexpected deviations or results can be broadly divided into two categories. One is a change in the social context. Social context includes politics, economics, demographics, Etc. The social context acts as a setting that influences the behavior of actors, organizations, Etc. Such a change in the social context may differ from the context judged as the optimal condition in the past, which may cause adverse outcomes different from those expected in the past (Vaughan, 1999). The other one is the impact of culture. Hopkins (2006) pointed out that organizational culture can influence the occurrence of accidents. Culture refers to the shared beliefs and perceptions inherent in an organization's daily practices and behavioral choices (Hofstede, 1997). Therefore, culture refers to dominant values and beliefs, and based on this, it influences the organization's daily activities and behavior choices, which can influence accident (Vaughan, 1999; Powell and DiMaggio, 1991; Granovetter, 1985)

Cultural factors can be approached by dividing them into the following two. One of the approaches to finding the cause of deviation of organizations is "New institutionalism". Powell and DiMaggio (1991) notes that organizational forms and actions reflect the dominant values and beliefs institutionalized within organizations. These dominant values exist as cultural environment and can influence actors' behavior in an organization (states, organizations, individuals). For example, a 'fantasy document'

systematically establishes an official response plan for an accident but is ineffective due to the uncertainty of the accident or disaster (Clarke, 1999). It shows that the firm belief that one can cope with all situations acts as a kind of cultural rule as an institutionalized value or belief within the organization (Powell and DiMaggio, 1991). Rules enforce the actions and choices of members in the institutionalized realm and provide legitimacy of organizational activities within the influence of culture. Another is the 'economic embeddedness perspective' approach, which explains how choices based on the value of economic benefits create organizational divergence (Granovetter 1985). This perspective presents those rational choices based on economics can lead to organizational deviance under certain circumstances (McKee and Black, 1992). For example, if a hospital downsizes its staff due to economic reasons, adverse outcomes may occur due to overwork and insufficient professional manpower (McKee and Black, 1992). In other words, they choose economic benefits rather than safety values.

Especially, the cultural factors presented above act as an external environment that affects the organization's activities, and this may lead to unintended or unexpected adverse outcomes. For example, if the economic benefits of an organization's choices can offset costs (from an economic embeddedness point of view), and if it is not regulated at a legitimate level (legitimacy), it may choose specific actions to achieve the organization's goals (Vaughan 1999). In other words, it is possible to secure legitimacy of organizational activities within the framework of regulation.

As such, regulation cannot always work successfully. Subjects subject to regulation may engage in acts that have secured legality within the regulatory boundary but may also violate regulations and pursue interests. This problem is also revealed in power relationships. For example, Ford's Pinto case is a case in which profit is pursued outside the framework of safety regulations (Lee and Ermann, 2014). Ford sold the car with safety issues, even though it deviated from federal safety standards in the design of the car and there was a risk issue. This is because the economic benefits of selling the product and compensating for defective designs outweighed the costs that would be gained as a result of regulatory compliance through the redesign of the product. Unlike powerful companies like Ford, organizations that cannot afford the consequences of regulatory violations have no choice but to comply with regulations. After all, the economic beneficiary choices of different organizations may succeed or fail depending on the relative power of the subject being regulated (Pearce and Snider, 1995; Vaughan, 1999). Alternately, the power of subunits may not be the same within the organization. If some subunits are relatively powerful, they can be an obstacle to pursuing common organizational goals (Fligstein, 1990). On the contrary, even if the subunits' power is the same, they can pursue their own goals, leading to failure to achieve the intended purpose of the entire organization (Giddens, 1984). Moreover, power relation appears in the process of interaction of various actors. The several sub-units that make up an organization can coerce or subordinate each other by power relation (Vaughan, 1999).

There are models that approach accidents and disasters by considering environmental factors and their impacts (Leveson, 2004; Rasmussen, 1997). Rasmussen (1997) applied environmental factors to

find the cause of package accidents. Factors affecting accidents were classified into each dimension. Each dimension includes 1) government regulatory factors, 2) regulatory oversight, 3) local government-related plans, 4) company safety rules, 5) driver's operation plan (safety check, transportation route selection, Etc.) and 6) surrounding elements (road width, external elements that can affect driving). Besides, it is meaningful that the root cause of the accident can be found through the mutual influence relationship between dimensions. This approach is significant in that it complements the top-down limitations.

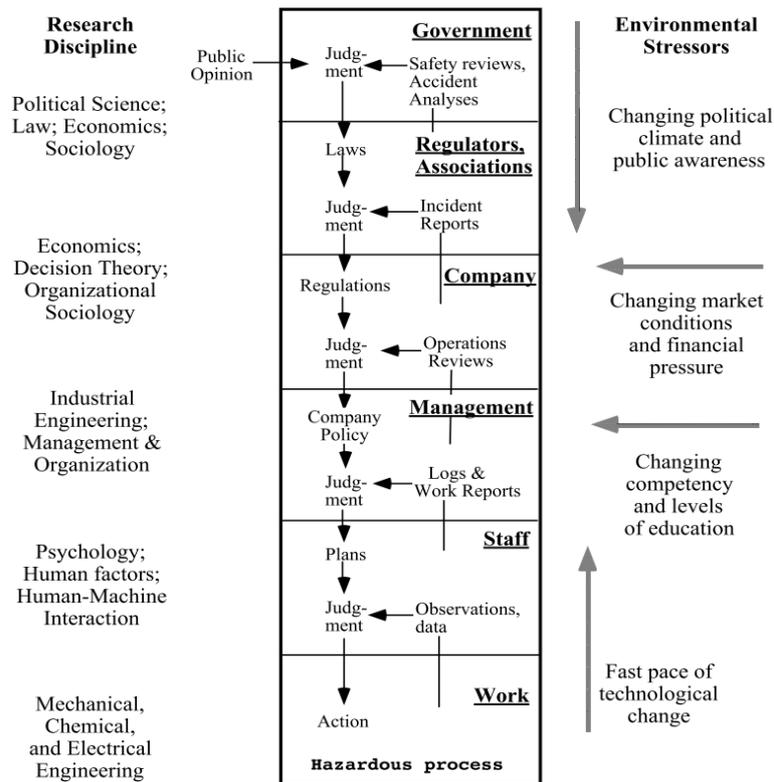


Figure 2.4 The Socio-technical system involved in risk management from Rasmussen (1997)

Leveson (2004) presented Systems-Theoretic Accident Model and Processes (STAMP). The approach points to the importance of a systematic approach to accidents. In particular, the analysis of the cause of the accident takes the position that the entire social structure in which the accident occurred must be considered. Social structure includes various factors such as government, regulation, policy, and organization that make up the social environment. The basic assumptions of this approach are the rapid change of technology in the new social structure, the nature of accident, interactions combined with complexity, new human errors such as operator error in the information that is not directly observed, and various policies such as regulatory factors that affect and lead to accidents. Besides, to ensure the

safety of the entire system, Leveson (2004) pointed out that it is necessary to eliminate the negative factors that affect the causes of accidents within the social structure.

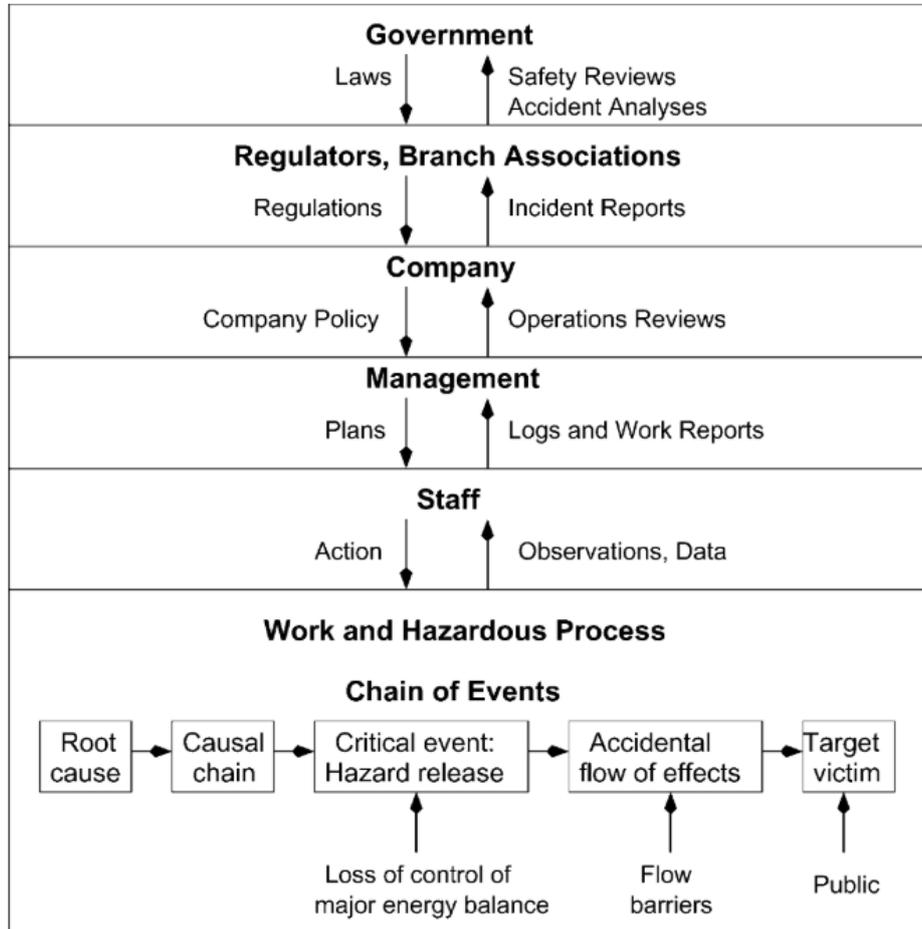


Figure 2.5 STAMP Modelling from Leveson (2004)

In this approach, information is exchanged through constant feedback (i.e., control loop). It is characterized by analyzing the impact on accidents by classifying aspects of developing or operating the system itself, compared to the existing approaches that view the system as one element. There is a characteristic that companies considered as individual actors, such as company managers and development teams, can be classified into various sub-factors to consider their influence.

2.5.2. Organization (structure and process)

1) Structure

In organizational theory, a structure is an anatomical structure that provides the basis for an organization to function and is completed by the interconnections of various subunits (Dalton et al., 1980). Organizations are made up of various members who function as subunits of the organization and

are connected and interact with each other (Vaughan, 1999). Organizational structures are complex, and accidents appear due to the interaction of internal parts within these complex structures (Perrow, 1999).

Organizational structures can sometimes be ineffective or inadequate in achieving organizational goals (Meyer and Rowan, 1977; Vaughan, 1999). The complexity increases with the organization's size, and in this case, it becomes more difficult to control the internal organization members. In addition, if the level of centralization and formalization of structures is increased, organizations may lack the flexibility to respond to unexpected events.

Communication problems due to the complex structures may be revealed. When the structure of an organization is complex and specialized sub-units are structured, the flow of information is complicated and knowledge about potential risks can be compromised (Freudenberg, 1992; Turner and Pidgeon, 1997). Vaughan (1996) described low information delivery and communication problem caused by structural limitation as 'structural secrecy'. Structural secrecy is the separation of knowledge or information about an organization's activities and goals by labor, class, and specialized division of the organization. Structural secrecy has three characteristics: First, information and knowledge for accomplishing organizational goals are always partial and incomplete by specialized members or sub-units. Second, when the corporate activities and information of the member(s) cross internal boundaries of sub-units, the possibility of being damaged or distorted increases. Separated knowledge and information reduces the ability to detect deviations occurring in organizational activities. Distortion of some information in communication in cooperation will lead to a loss of understanding of the organization's activities (Vaughan, 1999).

Several studies approach the occurrence of accidents by considering the characteristic(s) of the organizational structure. Concept of Normal accident from Perrow (1999) points out that technology itself is inherent complexity can be problematic within the organizational structure. For example, nuclear power technology and the technologies that make up each interior consist of complex interactions and tight couplings. It is because of these characteristics that accidents are inevitable. Therefore, these accidents are also called 'normal accidents' or 'system accidents.' 'Complex interaction' means that a set of simple technologies does not end with a single action and reaction, but each technology interacts with each other in a complicated way. In this case, where the problem occurred, it is difficult to identify and respond to the subsequent problems caused by the problem. 'Tight coupling' means that when one error occurs, it takes a short time to lead to the occurrence of another error due to the error. A tightly coupled system may not allow time to correct the error. For example, chemical leaks that can occur in chemical plants are tightly coupled so that a problem can be rapidly expanded not only to the factory itself but also to surrounding areas.

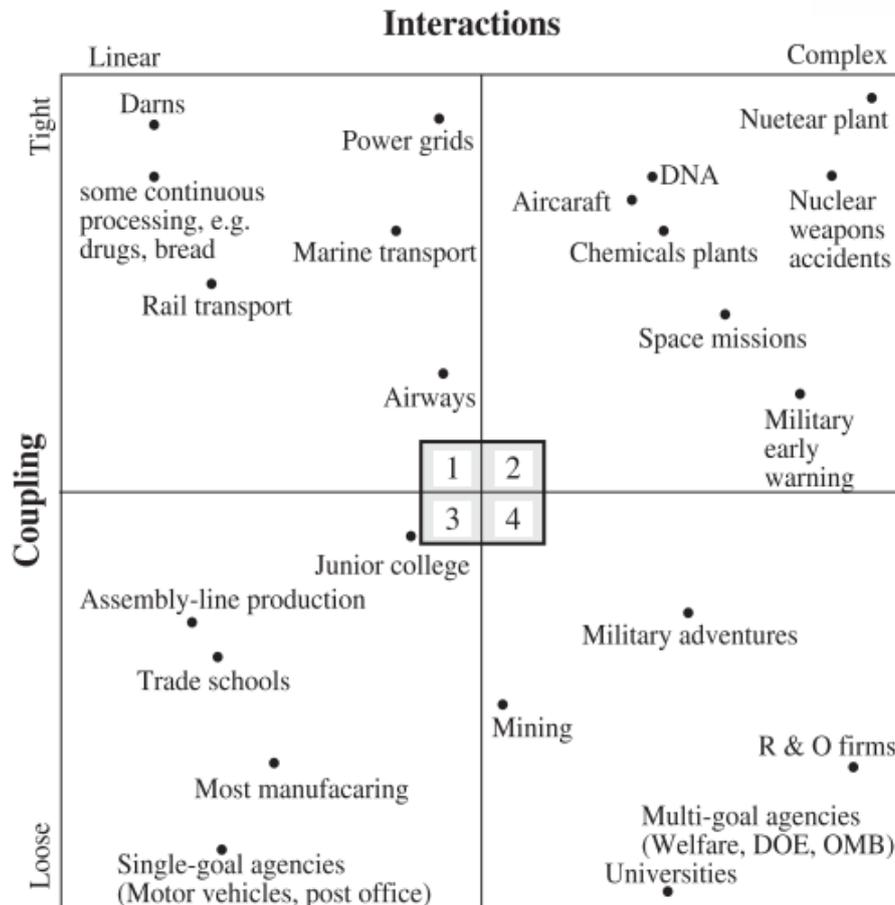


Figure 2.6 Classification of risk with Interaction and Coupling from Perrow (1999)

Vaughan (1999) presented a new interpretation of the 1986 Challenger explosion. Although the middle manager and the engineer's fault indicated in the committee's accident investigation report were pointed out, this issue is not a matter of personal immorality or lack of knowledge of the managers and engineers, but an organizational deviation that normally recognizes minor technical flaws as not being wrong and Points out that this is the result of the "normalization of deviance" process. In other words, mistakes occur within an organization or system because they perceive themselves as normal, not mistakes or defects. The author points out that complex organizations divide knowledge according to the division of labor, stratification, and expertise and that members of one department may not be able to properly understand the knowledge of the other departments and the entire system. In other words, it can cause problems of 'structural secrecy.' She pointed to the risk incubation process as another structural issue. Risk incubation means that dangerous mistakes are continuously repeated and accumulated, leading to disaster.

2) Process

“Process” describes the interactions among subunits within organization and how unintended suboptimal results are systematically produced (Vaughan, 1999). Subunits within an organization form a vertical or horizontal relationship with other subunits and interact with others. This horizontal and vertical relationship has limitations in simply explaining it as a structural factor. Various studies do not treat the relationships within an organization as a simple linkage but consider the interactions of the components within subunits of the entire organization (Edmondson, 2004).

The Socio-technical systems perspective assumes that the various elements that make up a system have a lasting effect on each other (Challenger and Clegg, 2011). In other words, the components inside the system consist of the constant interaction of the organization's goals, operating subjects, operational processes (procedures), infrastructure, technology, and cultural factors. Moreover, an accident is triggered by the interaction of the sub-factors that make up entire system. These interactions of subunits can create unintended large and small deviations. And deviation can accumulate and come out as a risk. “Deviance amplification” is the result of causal loops among interdependent subunits and feedback that makes any small deviation grow, with major unanticipated consequences (Weick, 1979; Vaughan, 1999).

Organizational processes leading to accidents or disasters have the following characteristics (Vaughan 1996). First, the influence of the environment may cause difficulties or pressure to achieve organizational goals. For example, conflicting goals, performance pressures, and deadlines can create a trade-off between productivity and safety and lead to accidents. Second, accidents or disasters go through quite a long incubation period (Vaughan, 1996). During this incubation period, the risks of small mistakes and deviations recognized as routine activities within the organization (Turner and Pidgeon, 1997), and it may be difficult to recognize the accumulated mistakes and deviations as sign of risks until it leads to an accidents or disasters. In this way, processes within an organization are interacting with various subunits with translated cultural beliefs and rules and can show up as unexpected or adverse outcomes (Vaughan, 1999).

Reason (2000) proposed High Reliability theory for effective accident prevention. A high reliability organization is characterized by an effective multiple defense system, an organizational culture that learns lessons from failure, and an organization that responds quickly to accidents. For example, it is an air traffic control system. High Reliability theory focuses on the processes in which human error affects accidents within an organization. Swiss Cheese Model as a system for preventing accident, emphasized the defense in depth of the system so that one mistake cannot lead to another big accident (Reason, 2000). However, there is also a limitation in the multiple defense system that one mistakes can continuously disable multiple shields.

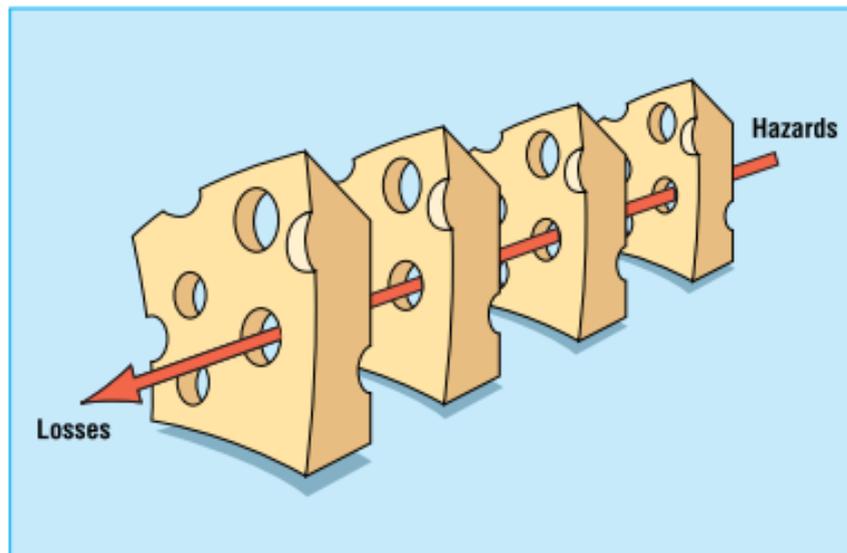


Figure 2.7 Swiss cheese model of James Reason from Reason (2000)

Human Reliability Analysis / Human Error Identification is applied to identify the error of human in organization. First, both HRA (Human Reliability Analysis) and HEI (Human Error Identification) methods were very influential in risk assessment in the 1980s (Dallat et al., 2019; Reason, 2000). It was used in investigations related to large-scale disasters such as the Chernobyl and Three Mile Islands explosion, highlighting the key role of human error (Kirwan, 1992).

2.5.3. Cognition/ choice

Cognition and choice are about how human error works and what choices are made by organizational culture and beliefs to actors. Recognition and choice can lead to intended or unintended consequences, which can also be the best or unanticipated negative outcome (Fischhoff et al., 1983; Reason, 2000; Vaughan, 1999).

Risk can be perceived as acceptable by members of the organization. Acceptable risks can be influenced by the uncertainty that actors perceive about the artifact of a particular technology, the cultural environment of the organization, and personal beliefs and values (Clarke, 1993; Vaughan, 1999). Vaughan (1996) suggested a 'normalization of deviance' for this concept. Normalization of deviance means that some members of an organization perceive a risk signal as normal under some influence of organizational cultures, and the risk signal is neutralized. Even if some members recognize the danger signal, the action is forced to choose based on institutionalized culture, and organizational beliefs and values are forced.

Various accident approach models deal with behavioral factors such as cognition/choice (Reason, 1997; Clarke 1993; Fischhoff et al., 1983). Human error is "the failure of planned actions to achieve

their desired ends-without the intervention of some unforeseeable event" (Reason, 1997, p.71). Human error is used to describe the result of members;' actions, the cause of an accident, and the choice taken by a people. For example, in the Chernobyl case, the operators wrongly violated plant procedures and switched off the safety system, thus creating a trigger for the nuclear plant explosion. Human errors can be divided into intentional violation and mistake, unintentional memory error (lapse), and attention error (slip) (Reason, 2000).

The HFACS (Human factors analysis and classification system) analyzes human error factors such as dangerous behavior and prerequisites for behavior. The general HFACS framework presented four levels and 12 causal factors (i.g., supervision and organizational impact). This approach was first applied in the 1997 aerial accident survey with human error factors such as pilots, flight attendants, and airlines and expands its scope to investigate railway transportation and maritime transportation accidents (Qiao et al., 2020).

According to Fischhoff et al. (1983), the question of acceptable risk is a matter of decision-making. In other words, the actor (individual or organization) is asked to choose among alternatives. Moreover, the choice depends on values, beliefs, and other factors. Therefore, there can be no one unified alternative representing the permissible dangers in society. The debate over acceptable risks becomes most evident when the participant is committed to distinguishing between matters of fact and matters of value. Nevertheless, a clear separation is often impossible. Facts about the situation in question and trust shape our values; Those values shape what we look for and how we interpret what we find. In this regard, subunits or internal members that make up an organization often underestimate the phenomenon. "Disqualification heuristic" prevents risk experts and decision-makers from accurately perceiving the likelihood of a failure. According to Clarke (1993), a disqualification heuristic is an "ideological mechanism or mindset that leads experts and decision-makers to neglect information that contradicts a conviction-in this case, a conviction that a sociotechnical system is safe."

2.5.4. Cause of accident

The approach to the cause of the accident has traditionally been dealt with the risks of the technology itself. The fault tree approach (or analysis) is a typical technical approach. Fault Tree Analysis (FTA) is a method of classifying events and factors and finding errors related to the root cause of the accident (Čepin and Mavko, 2002). In particular, the process of technology operation is expressed as an event tree and technical defects or problems that can occur when each technology is operated. Recently, Kim et al. (2019) classified potential risks in the technology and conducted a fault tree analysis to evaluate the PCS part of ESS's stability. After classifying and modularizing the components constituting the PCS according to the function, risk factors that could cause a specific event (i.g., when DC short-circuit occurs, disconnection of other parts) are presented in each module.

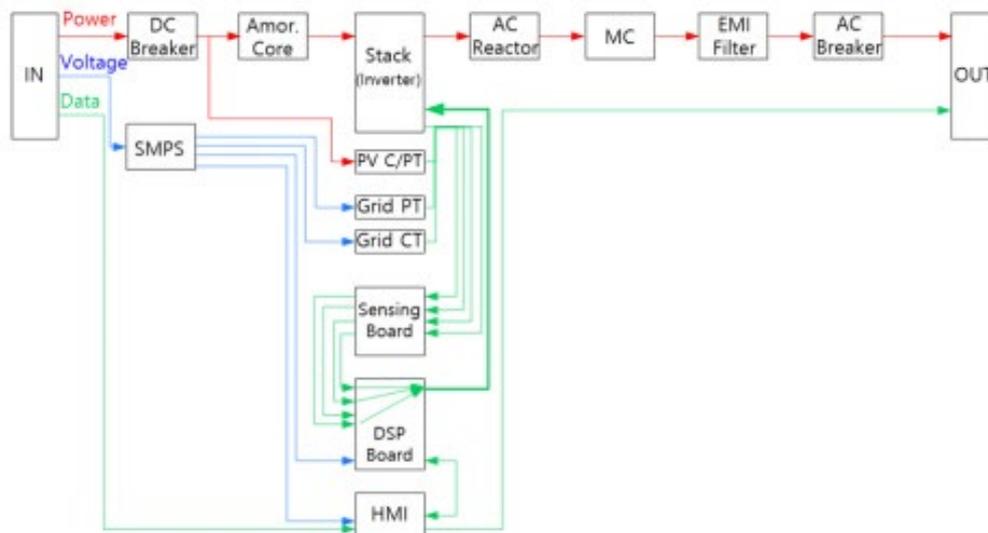


Figure 2.8 Consist of modeling for PCS on ESS from Kim et al. (2019)

Event chain model is that events considered almost always involve some component failure, human error, or energy-related event. The chains may be branching, or there may be multiple chains synchronized using time or common events (Benner, 1975). Event chains developed to explain the accident usually concentrate on the proximate events immediately preceding the loss. This approach focuses on 'initiating events' and 'root cause' and finding out who is wrong and responsible for it.

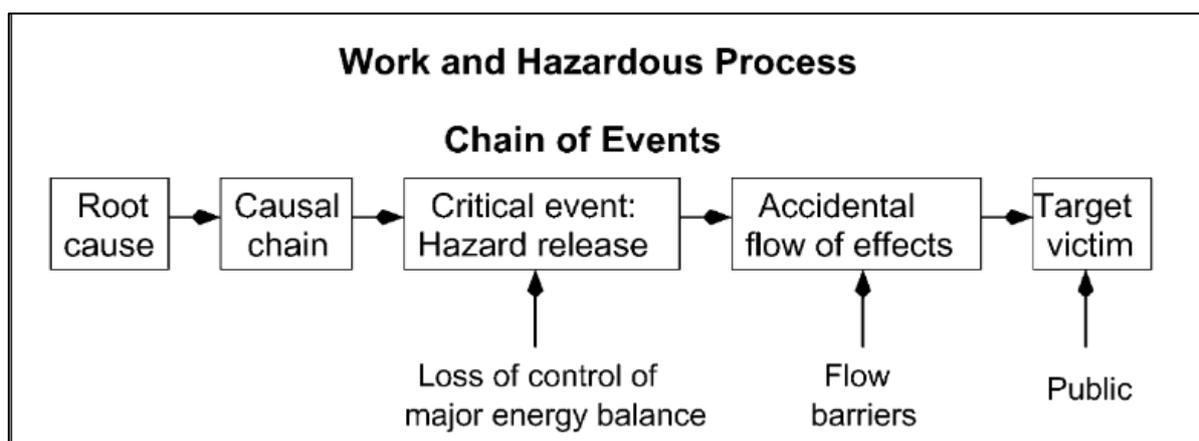


Figure 2.9 Work and Hazardous Process Chain of Events from Leveson (2004)

2.6. Summary

In energy transition, ESS has increased in importance because it can impede RE's intermittency RE. ESS stores electricity through batteries and supplies them when needed. However, batteries have a fire hazard. Korea promoted the expansion of ESS supply through various support policies. In the midst of the rapid increase in ESS installations, 28 continuous fires occurred and became a social issue. The government conducted two fire investigations but announced the investigation results focusing on defects in the engineered body. However, experts pointed out the limitations of controversial issues and insufficient result of fire investigations.

The domestic ESS installation process has the following characteristics. First, it is a short commercialization process of the technology. According to MOTIE (2014), Korea government is conducting pilot projects (2009) such as Energy Independence Island and Jeju ESS Test Bed (2012). Commercially available ESS may not have been fully tested under various conditions since ESS installation rapidly increased in 2018. Second, it is the government's support policy. The government provides full support from the public to the private sector by establishing mandatory public institutions, special rate discounts, and REC weight incentives. Eventually, ESS installations are increasing rapidly through this. In addition, there are limits to regulations to ensure the safety of ESS. Comparing domestic and overseas ESS-related safety standards, Korea has a limitation that it is too general and has low enforcement.

Research related to ESS is given and can be divided into two types. First, these are studies on the concept of ESS and the use of technology. It deals with the concept and internal design of the entire system. And it is a study on the connection and utilization plan of ESS system and renewable energy. Second, it is a study on the fire risk of ESS. ESS deals with securing technical safety for fire hazards of batteries and investigating defects for actual fires (causes). However, since the research is mainly focused on technical causes, there is a limit that it is difficult to access the causes of fundamental accidents that occur in the process of technology development and adoption in society.

To overcome the limitations of the technology deterministic accident investigation, the cause of the ESS fire accident is explored by applying Social Construction of Technology. From perspective of SCOT, "Relevant Social Groups" and "Social environment" affect technology adoption in society. Each relevant social group understands the technology through their own flexible interpretations and decides the final form of the technology through negotiations that close the gap in the understandings. When this technology is adopted, it will undoubtedly be used as a Black box. A full review will be conducted by reopening Black box when accidents or disasters occur. Based on perspective of SCOT, the concept of usability is used to find directions for better development of the technology.

However, to overcome the limitations of SCOT and comprehensively review the technology, the concept of various accident models considering social factors can be used. The accident investigation

models reviewed here consider social impacts and cover a wide range of disciplines, including organization, human behavior, and technology. These models attempt to explore and identify the social context that affects organizations, people, and technology and the interactions of the social changes. The process of approaching concepts and accidents used by these accident models is very similar to examining the structure and 'Black box' in which 'related social groups' used in SCOT and STS.

This study examined various theories and approaches to find the cause of an accident or disaster by socially constructed technology. Previous research deals with boundary ranging from traditional approach models focusing on the cause of accidents to systematic approaches to accidents. Some researches that consider the mutual influence of accidents and social structural factors (environment, organization, cognition) have become dominant (Perrow, 1984; Vaughan, 1997; Reason, 1990). 'Environment' category deals with the set of organizational factors (organizations' network and interconnections) and external factors (policy, technology, economics, and culture) that can influence organizational activities, goals, and outcomes (Hall, 1996; Powell and DiMaggio, 1991; Rasmussen, 1997; Leveson, 2004). Environmental factors examine the interaction of accidents with various surrounding factors such as institutions, politics, technology, economy, law, demographics, and ecology. Organizational characteristics can be classified into structure and process. 'Structure' is an anatomical structure that can provide the basis for an organization to function, and the entire structure is completed in the form of a combination of various subunits. This explains information transfer, communication, and collaboration between the upper and lower units of the organization. 'Process' is Systematic production of intentional or unintended outcomes arising from the interactions between sub-units that consists of the organization. In this 'Organization' category, it examines how suboptimal outcomes that may arise through this structure and process are formed and handled. 'Cognition/choice' category explain cognitive behavior leading to best, suboptimal, or adverse outcomes that are influenced by the organization's dominant value and beliefs. by the related social groups within organization. Lastly, 'accident cause' category explore the direct defect (technology) that caused an accident or disaster in perspective of Technological determinism. The following table lists the different approaches in each category.

Table 2.3 Classification of approaches

Category	Author	Main contents	Assumption
Environment	Hall (1996)	Environment as organizational set and a social context -External factors can lead to suboptimal outcomes such as accidents with environment set.	Environmental uncertainty which can lead to unintended consequences.

	Powell and DiMaggio (1991)	Institutionalized organization -Organizational forms and actions reflect the dominant values and beliefs	These values and beliefs influence the choice of the actor.	
	Granovetter (1985)	Economic embeddedness perspective -Relationship between rational choice centered on economic interests and organizational deviation	Economical and rational choices can create adverse result in specific condition (safety Vs. profitability).	
	Rasmussen (1997)	Socio-technical system - Considering external factors other than the direct cause of the accident - Regulatory factor	The influence of environmental factor such as government, company, operator.	
	Nancy Leveson (2004)	Systems-Theoretic Accident Model (STAM) - Social environment refers to government, regulation, policy, and organization. -Possibility of new types of human error that can occur in the rapidly changing social environment	Entire social environment in which the accident occurred must be considered for analyzing cause of accidents.	
Organization	structure	Perrow (1999)	Normal Accident Theory - Sequential occurrence of technological failures with tight or loosely coupled in the system	Accidents are inherent characteristic of complex and tight system due to the structural combination of technologies.
		Vaughan (1999)	Structural secrecy - Inefficient communication with transferring partial & incomplete information	Organizational structure defects (Complex organization, lack of communication)
	Process	Challenger and Clegg (2011)	Socio-technical systems theory - Continuous interaction inside the system with goal, operational procedure, operational subjects, and cultural elements. - Disasters gathered by chain reactions of small problems	various elements that make up a system have a lasting effect on each other.
		Reason (2000)	High reliability theory -Multiple defense system (Defense in depth) - Interconnected active(people) and latent condition failures	The multiple defense system that one mistakes can continuously disable multiple shields.
		Weick (1979)	Deviance amplification -Causal loop within organization	Small deviation grows, with major unanticipated consequences.
	Cognition / Choice	Reason (2000)	Human error - Slip, lapse (Unintentional) - Mistake, violation (Intentional)	

	Fischhoff et al., (1983)	Acceptable risk - Influenced by individual or organizational values and beliefs	
	Vaughan (1996)	Normalization of deviance - organizational deviance is considered as normal event	Organizational culture has forced to perceive risk signal as usual event.
	Clarke (1993)	Disqualification heuristics - Information that is contrary to the beliefs and values and decision makers ignore or underestimate the information on risk	Objective perception of real risk cannot be achieved.
Accident cause	Čepin and Mavko (2002)	Fault Tree Analysis - Explore defects and errors for each component of technology and analyze causal relationships with accidents	Malfunction of the technology itself.
	Benner (1975)	Event chain model - 'Root cause' or 'initiating event' - An accident occurs due to one critical cause or starting event	One initiating cause is the beginning of 'accident'.

3. Method

3.1 Research framework

The purpose of this study is to comprehensively analyze fire accidents by considering the influence of social factors that can generate technical defects or have another negative effect rather than the causes identified as direct technical causes of ESS fire accidents. Prior research related to ESS is mainly focused on uncovering technical defects and suggesting improvement measures. Therefore, this research analyzes how ESS was socially constructed from the perspective of SCOT and what effect it had on the fire occurrence. The following hypotheses were established to examine the research questions. First, ESS is a socially constructed technology. Second, continuous fire accidents are adverse outcomes due to the interaction of major stakeholder groups of ESS.

SCOT describes the final adoption of technological artifacts by interacting with relevant social groups with different understandings of technology (Bijker et al., 1987; Sismondo, 2011). The various groups that use technology are “relevant social groups” (RSG) with technology. The social groups each have some specific meanings for technology with “flexible interpretations”, and conflicts may arise depending on the interests of each group (Bijker et al., 1987; Latour, 1987).

ESS can be constructed by related stakeholders. These RSGs include a variety of stakeholders, including government and various corporate and private power generation operators. So, RSGs have flexible interpretations of ESS according to the interests of each group. Differences in the interpretation of technology among each group create conflicts and go through “negotiation” to resolve them. As a result, ESS becomes a technical artifact by the final agreement and adoption of RSGs. In other words, the last result of the socially constructed technology results from conflicts of interests and negotiation.

Latour (1987) explained the technological artifacts produced through the interaction of RSGs and how they are utilized through the concept of Black box. The final adoption form of a technical artifact is what survives the competitive interaction of groups according to their linkages and power relations. Therefore, the groups perceive these technical artifacts as Black box of robust, reliable, and undoubtedly usable scientific fact (Callon and Latour, 1981; Latour, 1987). Black box can be reexamined entirely due to an accident or disaster (Beck, 2008). Therefore, to find the cause of ESS fire accident, it is necessary to explore the interaction in the Black box. However, SCOT only explains the complexity of interaction such as negotiation among RSGs and does not provide sufficient explanation for the interaction details. To supplement this limitation and examine the relationship between the interactions of the social groups and the impact of fire accidents, various accident approach models that consider social factors will be utilized.

Some accident approach models reviewed in the theoretical background consider accident with social factor's impact together. Moreover, it covers various fields, including organizations, human behavior, and technology as factors interacting with the social environment. For example, Vaughan

(1999) analyzed how organizational characteristics influence accidents with environment, organization, and behavior concepts. The analysis of this research uses these concepts to explore the adverse effects and results of interactions that exist inside Black box.

RSGs reflect their interest in technical artifacts and make them socially adaptable through various strategic actions such as conflicts and negotiation. Depending on the power of each group, these strategic actions can lead to either facilitating or limiting other groups' behavior (Sismondo, 2011; Song, 1999). For example, ESS is designed and produced by different social groups in tight cooperation. The interaction between battery manufacturers, electrical control product manufacturers, private power generation operators, and the government in the ESS production process is quite similar to the relationship between accidents and organizations revealed in Vaughan (1999)'s Challenger accident approach.

Therefore, the main conceptual factors of various accident approach models are operationally defined and applied in the research framework and the causes of ESS fire accidents are analyzed. The research framework is divided into two main parts. The first part examines the mechanism by which ESS is socially constructed. This part recognizes that ESS fire accidents are a social structural problem and sets a direction to approach the fire causes. The other is to comprehensively review the socially constructed ESS technology that was perceived as Black box. The main concepts of the accident approach models are applied to analyze the causes of fires.

First, it concerns the mechanism by which ESS is socially constructed. It is necessary to define the concepts of RSGs, Social environments, and interactions such as conflicts and negotiation based on flexible interpretation of ESS technology. RSGs are classified to internal component manufacturers, private generation operators, government, and other stakeholders. RSGs are connected around the technical artifact (ESS) and have the characteristics of interest groups pursuing their own goals. Social environment is an external factor that affects the social composition of the ESS. Social environment consists of related policies, regulations, and cultures of groups. In summary, social groups are interest groups that pursue their own goals through ESS, and they interact with the Social environment. RSGs (Battery manufacturers, Electrical control products manufacturers, Private power generation operators and Government) determined the final adoption of ESS, and they play significant roles in the social construction of ESS technology within Social environment. RSGs have flexible interpretations of ESS technology according to their respective interests and goals and adopt the final technical artifact through conflicts and negotiations. As a result, the socially constructed ESS technology has been adopted and utilized broadly as Black box that is accepted and used without doubt or question on the technology itself.

Second, the effect of RSGs' interactions (conflicts and negotiations) on ESS fire accidents is analyzed. The inside of Black box is composed of the consequences of the interaction with Social environment's influence. Accordingly, the interactions of RSGs were analyzed by utilizing the concepts

of Environment, ESS organization, and Cognition/ choice. However, it is challenging to apply these concepts directly in the research framework. Because the field to which the concepts are applied and the subject of research are different. Therefore, the concepts are operationally defined and used for analysis.

Environment is operationally defined as an external factor that influences the goal achievement of relevant social groups. Environment includes Social context and Culture. Social context refers to external factors such as policy and economy. Culture is the dominant values and shared beliefs of social groups. Both can change the environment and influence the social group's goal-accomplishment.

ESS organization is also defined as Technology-interest alliance, where RSGs are interest pursuing groups, and interact with each other to accomplish their goals such as economic profits within ESS organization (Duysters and Hagedoorn, 1998; Stevenson et al., 1985). Groups can have organizational characteristics through the form of "Coalition" organization (Stevenson et al., 1985), and various corporations can make technology-alliances to achieve goals such as technological innovations organization (Duysters and Hagedoorn, 1998). ESS organization is divided into two sub-concepts. One is the Structure of ESS organization. The connected form of social groups could negatively affect communication and mutual information transfer and can create causes of accidents. The other is Process, which means that unexpected adverse outcomes occur due to interactions among RSGs.

Cognition/ choice of members of RSGs is behavioral factors that influence behavior choices. The perceptions of members can be influenced by the dominant values and shared beliefs of the culture. In this way, members can disqualify the actual risk of ESS technology and lead to fire accident. Research framework is as follows.

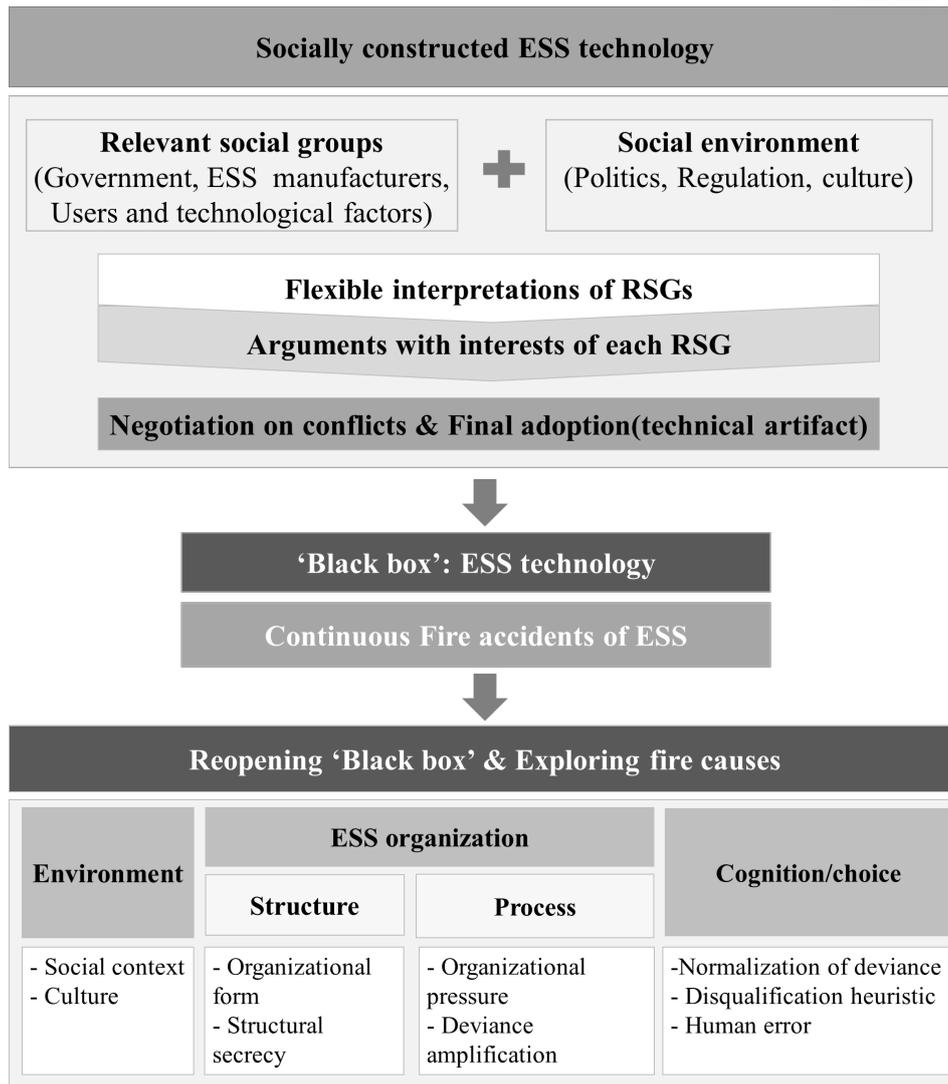


Figure 3.1 Research framework modified from Bijker et al. (1987), Bijker and Law (1994), Latour (1987, 1999), Perrow (1999), Pinch and Bijker (1984), Reason (2000), Vaughan (1996, 1999)

As mentioned above, it is necessary to examine the interactions of RSGs to find the causes of fire accidents. Vaughan (1999) points out that the organization can lead to mistakes, misconduct, and disasters by Environment, Organization, and Cognition/ choice. Unanticipated adverse outcomes may occur due to the structural complexity and interaction of subunits constituting an organization or system. For example, failure of the organization or system can occur due to not only technical defects but also human errors, environment, culture, and organizational structure (Reason, 2000; Perrow, 1999; Vaughan, 1999).

Therefore, the interactions in Black box are analyzed with Environment, ESS organization, and Cognition/ choice. In addition, various concepts used in accident approach models supplemented details of RSGs' interactions. For example, disqualification heuristic, a concept included in Cognition/choice, is related to ESS fire risk. When ESS organization members underestimate the fire risks, it leads to a

fire accident. Moreover, the underestimation of risk can be influenced by Culture, sub-concept of Environment, because Culture is the Shared beliefs inherent in the choice of members of the ESS organization and can directly or indirectly affect the risk perception of the members. As such, the main concepts about interactions constituting Black box influence each other and can cause fires. The following table contains the interactions of RSGs that can cause fire accidents.

Table 3.1 Detail of Black box and cause of fire

	Environment	ESS organization (Technology-interest alliance)		Cognition/choice
		Structure	Process	
Operational definition	The external factors (policy, economy and culture) can affect organizational activities, goals & outcome (Hall, 1996).	An alliance of relevant social groups linked by technology and their interests (Duysters and Hagedoorn 1998).	Systematic production of intentional or unintended outcomes arising from the interactions between sub-units (Vaughan, 1999).	Member's cognitive behavior leading to best, suboptimal, or adverse outcomes (Reason, 2000; Vaughan, 1999).
ESS Fire Causes	<p>Social context (Hall, 1996) -Effect of Political, economic, legal, ecological environment</p> <p>Culture - Dominant & shared belief or perception inherent in organizational daily activities (Hofstede, 1997) -New institutionalism: institutionalized dominant values & beliefs became cultural rule and obtain legitimacy (Powell et al., 1991; Perrow, 1999) -Economic embeddedness perspective: undermining safety for economic interest (Granovetter, 1985) -Regulation: establishment of safety standards with Power hierarchy with dominant sub-units (Vaughan, 1999)</p>	<p>Organizational form - Complex combination of different technologies (Coupling & interaction in artifact) (Perrow, 1999)</p> <p>Structural secrecy & Communication (Vaughan, 1999) -Partial & incomplete knowledge due to different professionalism between sub-units (i.g., Majors) - Low Information transfer (different term) : decreased ability to detect routine non-conformity</p>	<p>Accomplishment pressures - Factors that influence the achievement of the organization's goals - Conflicting goals, performance pressure, deadline (Vaughan, 1999) - Latent condition (Reason, 2000)</p> <p>Deviance amplification - Interdependence and feedback that makes any small deviation grow in organizational system (Weick, 1979; Vaughan 1999) - Accumulation of small deviations for long period (Turner 1978; Vaughan, 1996)</p>	<p>Normalization of deviance (Vaughan, 1996) -Neutralize signal of danger - Irrational choice (Pursuing organizational goals despite personal objection)</p> <p>Disqualification heuristic (Clarke, 1993) - Acceptable risk with uncertainty based on personal beliefs and values (Fischhoff et al., 1983)</p> <p>Human error (Reason, 2000) -Slip, lapse, mistake, violation (Insufficient expertise and experience)</p>

3.2 Research design

The research subject is 28 ESS fire accidents that occurred in the last three years. ESS fire accidents are a unique case where continuous fires are concentrated in a specific period, unlike general fires. The analysis of this case uses both qualitative and quantitative research methods. This research applied Case Study, one of the qualitative research approaches. Case Study approach collects various information and in-depth data for a specific case with one boundary and derives case description and case theme (Creswell et al., 2007). Therefore, Case Study approach is suitable for identifying specific cases, such as ESS fire accidents, and investigating detailed descriptions of what needs to be known. Case studies collect data using multiple forms. For example, a researcher can collect and analyze various data such as interviews, observations, documents, and audiovisual data (Creswell et al., 2007). Through this research approach, social structural factors influencing the research subject are reviewed, and the underlying primary meanings and theoretical explanations are provided (Creswell and Creswell, 2017).

This research conducts Thematic Analysis (TA) based on interview data on members of RSGs on ESS fire. TA can find the primary meanings of interviews through collecting qualitative data, such as cultural and contextual messages (Vaismoradi and Snelgrove, 2019). TA conducts the theme development process based on the researcher's interpretation and judgment and derives shared meaning and the latent content in the qualitative data (Vaismoradi and Snelgrove, 2019; Braun and Clarke, 2020).

Subjects of this research are ESS industry workers and experts in related fields with sufficient experience and expertise in ESS technology. Interviews were conducted with battery manufacturers, electrical control product manufacturers, private power generation operators (fire victims), academic experts, and the investigation committee member. Based on the research framework, the interview data are analyzed in depth.

This study utilizes a mixed-method methodology (Creswell and Creswell, 2017). First, through newspaper articles and reports, related issues are collected, and major issues are derived. Based on this, we collect interview data for in-depth analysis. Interview subjects of this research are ESS industry workers and experts in related fields with sufficient experience and expertise in ESS technology. The exploratory approach derives major issues from the collected interview data using semantic network analysis. Based on this, for in-depth analysis, thematic analysis is performed on the interview data.

The entire research design and details are as follows. First, Pre-research was conducted to review official government statements, news, and similar fire cases related to the ESS fire accident. Second, based on the pre-research result, semantic network analysis is conducted based on interview transcripts on fire accidents with ESS technology. NetMiner 4.3.0.b was used for semantic network analysis of textualized interview dates. The program provides exploration and analysis of linguistic data and provides visual network model construction and data mining (Cyram, 2017). Third, interview materials are analyzed by thematic analysis. The process of developing the 'theme of qualitative interview

materials is carried out. Theme development contains theme, code, and key data on ESS technology and fire causes.

3.3 Data collection

This research collects factors affecting the cause of fire based on official investigation reports and related literature data and collects qualitative data to derive various and abundant experiences and issues that were not revealed in literature data. First, the government's official fire investigation report was analyzed to investigate ESS fire causes. There are some technical causes and a few organizational factors that interact with social context. However, the literature data have limitations in understanding the impact of social factors such as society, policy, and culture on technical causes of ESS fire accidents. Second, interviews were conducted to supplement these limitations and collect qualitative data. Through an interview, it is necessary to collect vivid opinions from various fields to examine stakeholders' debates on the cause of the fire.

Interviews were conducted from July 03 to November 27 by using face-to-face interviews, video conferences, and telephone interviews. A total of 24 interviewees consisted of the battery industry, the electric and electronic industry, the victims of ESS fire accidents, and others (academia, researcher). The interview aims to find RSGs' latent and shared meanings and different interpretations on ESS technology. The sample collection criteria are those in the ESS and battery industry and actual ESS fire victims. The first interviewees who met the sample collection criteria were found through the introduction of acquaintances, and the initial interview was conducted. Subsequent respondents were identified through snowball sampling. Since the interviewees were recruited through the social network of the initial interviewees, major and work fields were considered to complement the criteria of the samples. The characteristics of the interviewees are as follows.

Table 3.2 Characteristics of Interviewees

No.	Division code	Date	Major	Field	Remarks
1	A	20.07.03	Electric control	EPC	
2	B	20.07.03	Others (Physics)	EPC	
3	C	20.08.18	Electric control	Electric control (PCS)	
4	D	20.08.18	Electric control	Electric control (BMS)	
5	E	20.10.21	Chemistry	Others	Fire prevention facilities
6	F	20.11.02	Others (Business management, BM)	Battery	CEO

7	G	20.11.03	Chemistry	Battery	
8	H	20.11.04	Chemistry	Battery	
9	I	20.11.05	Electric control	Electric control (PCS)	
10	J	20.11.05	Electric control	Electric control (BMS)	
11	K	20.11.05	Electric control	Electric control (PCS)	
12	L	20.11.06	Others (Architecture)	Others	Public electric company
13	M	20.11.12	Chemistry	Battery	
14	N	20.11.13	Chemistry	Battery	
15	O	20.11.13	Others (BM)	Fire victim	
16	P	20.11.19	Others (BM)	EPC	CEO
17	Q	20.11.19	Others (BM)	Fire victim	
18	R	20.11.22	Others (BM)	EPC	CEO
19	S	20.11.24	Others (BM)	Others	Research Institution
20	T	20.11.26	Electric control	Fire victim	
21	U	20.11.26	Electric control	EPC	
22	V	20.11.27	Others (BM)	EPC	CEO
23	W	21.01.27	Chemistry	Battery	University
24	X	21.01.27	Chemistry	Battery	The investigation committee

Main interview questions were composed by reflecting existing government ESS fire accident reports and related issues. Through semi-structured questions, various opinions of experts on the causes of ESS fire accidents were obtained. The main contents of the interview are as follows. The main contents of the interview are as follows: 1) Causes of ESS fires, 2) Fire risk of ESS, 3) Inter-company cooperation for ESS product (each specialized field), and 4) Other thoughts (overall other opinions on ESS and accident).

3.4 Analysis process

This research applies a comprehensive approach to the effects of social factors that have influenced ESS fire causes. In particular, the effects of Social environment such as policy, economy, and culture on RSGs were reviewed, and the consequence of interactions leading to fires for accomplishing the goal

of each RSG was explored. The analysis process takes a deductive approach. It consists of literature review, Thematic Analysis, Semantic Network Analysis and conclusions.

First, step is examining the socially constructed process of ESS technology and final technological artifacts with external environmental factors and RSGs. ESS technology can be affected by external environmental factors (policy, economy, technology) that have affected the mechanism of SCOT. Government policies can have a significant impact on the diffusion of new technologies. There is ESS industry reaction due to the influence of policy factors. Therefore, the government's official report, policy-related press paper, and newspaper articles are used to analyze changes in ESS-related policies and how they influence the market's formation and change process. In particular, economic incentive policy has significantly impacted the rapid increase of ESS installation and industry expansion. Since strong incentive policies can act as a social context that induces the private sector's capital inflow, a profitability simulation is conducted.

Second, semantic network analysis was conducted on qualitative interview data to explore significant issues about ESS fire accidents. Semantic network analysis utilized NetMiner 4.3.0.b. Interview materials are converted into text, and the primary meaning is derived through coding, grouping, and categorization. Through semantic network analysis, it visualizes the connection of major nodes (keywords) revealed in interviews. Especially, it confirms the difference between the modes of the entire 'ESS organization' and each network of relevant social groups.

Third, TA is performed to derive the significant meaning of the qualitative interview data. Through the qualitative analysis of the interview data, the characteristics of 'ESS organization' and sequential fire accidents are analyzed. The analysis aims to find potential content and critical meanings hidden in interview materials through the theme development process. In particular, the interaction of several RSGs utilizing ESS technology was analyzed with a focus on what leads to continuous fire accidents.

4. ESS fire case and official investigation

Because continuous fire accidents have become a social issue in Korea, the government launched a “public-private joint ESS fire accident cause investigation committee” to conduct accident investigations. Due to the characteristics of the battery fire, most of the accident sites were burned down. Accordingly, the committee faces difficulties in investigating the causes through site visits. The committee collected as much relevant data as ESS monitoring records, interviews with business workers, and on-site visits. Moreover, they reviewed the possibility of technical fire causes in the overall ESS, such as batteries, PCS, and BMS. In addition, the possibility of fire-related to expertise in ESS installation and operation was also reviewed. The committee suggested: 1) insufficient battery protection system against electric shock, 2) insufficient ESS integrated control and protection system, 3) poor management of the operating environment, and 4) negligence of installation, as the fire causes. The results of official government fire investigations are as follows.

Table 4.1 ESS Fire accident official investigation results Modified from MOTIE (2019), MOTIE (2020)

	1st investigation	2nd investigation
Investigation Period	‘19.01 ~ ‘19.06	‘19.10 ~ ‘20.02
Subject (date)	23 fire cases (‘17.08 ~ ‘19.05)	5 fire cases (‘19.08 ~ ‘19.10)
Causes of fire	<ul style="list-style-type: none"> - Insufficient battery protection system - Insufficient management of the operating environment - Installation error - Insufficient integrated control and protection system inside ESS <p>Cf. Some batteries had technical defects, but not a direct link to fire.</p>	<p>- High probability of battery failure (Estimated fire caused by the</p> <p>Combination of harsh operation of ESS and battery failure under high SoC of battery)</p>
Safety measure	<ul style="list-style-type: none"> - Establishment of KC and KS - Mandatory installation of safety devices (inducing outdoor installation) - Supplemental safety measures (firewall installation, Etc.) 	<ul style="list-style-type: none"> - Charge rate restriction (lower SoC) - Support for outdoor relocation of internal facilities - ESS operation data record keeping - Establishment of emergency order regulations (demolition, relocation, Etc.)

It is a controversial issue that the cause of the fire pointed out in the first investigation has changed at a second investigation. Although defects were found in some battery cells in the first official investigation, it was concluded that the possibility of causing self-ignite on the battery was very low in a fire accident simulation (MOTIE, 2019). However, the results of the second investigation concluded that batteries were the direct cause. Major battery manufacturers, LG Chemical, and Samsung SDI conducted the same fire test on the presumed evidence of internal ignition pointed out as a direct cause of fire and presented opposite result compared to the government's investigation result (Kim, 2020a).

Some industry experts pointed out that the current government's official investigation results did not properly identify the actual cause of the fire (Kim, 2020b). Therefore, controversy arose as the government's second investigation result presented contradictory contents.

There may be stakeholders who are not satisfied with the results of this fire investigation. However, the currently published report of the investigation results has limitations in that it is mainly composed of technical experts in terms of the independence of the investigation committee and the composition of the investigation committee. These limitations may not examine the negative impact of related policies or provide a sufficient explanation for the impact of social context. The government's official fire investigation revealed the following limitations. First, there is a limitation in that it was rushed to reveal the technical flaws of ESS (Kim, 2020b). Most of the investigation committee consisted of technical experts, and the limited investigation period was not enough to comprehensively approach the technical and social causes of fire accidents. Second, two official investigations presented contradictory results on the fire possibility of batteries, which are major components of ESS (MOTIE, 2019; MOTIE, 2020), so there are reliability issues of the official investigation results. Third, although the accident investigation committee should be independent to present objective and fair results (Roed-Larsen and Stoop, 2012), it lacked independence because official investigations were affected by the government, for example, the composition of committee members. Due to these limitations, it may be difficult to provide a sufficient explanation for the various interactions of related stakeholders that occurred in developing and socially adopted ESS technology and the factors that contributed to the fire accident.

To learn more about ESS fires, accidents were classified based on Region, MWh (Capacity), Type of energy, Location, Date of accident, ESS operation period, and Type of accident. The status of ESS fire accidents is as follows.

Table 4.2 ESS fire accident status Modified from MOTIE (2019), MOTIE (2020)

No.	Region	MWh	Type	Location	Building	Date	Operation	Condition
1	Gochang	1.5	Wind	Seacoast	Container	17.08.02	-	installing (in storage)
2	Gyeongsan	8.6	Frequency & peak control	Mountainous district	Container	18.05.02	1 year 10 months	under repair
3	Yeong'am	14.0	Wind	Mountainous district	EPS (Expanded polystyrene) panels	18.06.02	2 years 5 months	under repair
4	Gunsan	19.0	Photovoltaics (PV)	Seacoast	EPS Panels	18.06.15	6 months	Standby after charging
5	Haenam	3.0	PV	Seacoast	EPS Panels	18.07.12	7 months	Standby after charging
6	Geochang	9.7	Wind	Mountainous district	EPS Panels	18.07.21	1 year 7 months	Standby after charging

7	Sejong	18.0	Frequency & peak control	Factory area	EPS Panels	18.07.28	-	installing
8	Yeongdong	6.0	PV	Mountainous district	EPS Panels	18.09.01	8 months	Standby after charging
9	Tae'an	6.0	PV	Seacoast	EPS Panels	18.09.07	-	installing
10	Jeju	0.2	PV	Commercial area	Concrete	18.09.14	4 years	Charging
11	Yong in	17.7	Frequency & peak control	Factory area	Container	18.10.18	2 years 7 months	under repair
12	Yeongju	3.7	PV	Mountainous district	EPS Panels	18.11.12	9 months	Standby after charging
13	Cheon'an	1.2	PV	Mountainous district	EPS Panels	18.11.12	11 months	Standby after charging
14	Mungyeong	4.2	PV	Mountainous district	EPS Panels	18.11.21	11 months	Standby after charging
15	Geochang	1.3	PV	Mountainous district	EPS Panels	18.11.21	7 months	Standby after charging
16	Jecheon	9.3	Frequency & peak control	Mountainous district	EPS Panels	18.12.17	1 year	Standby after charging
17	Samcheok	2.7	PV	Mountainous district	Concrete	18.12.22	1year	Standby after charging
18	Yangsan	3.3	Frequency & peak control	Factory area	Concrete	19.01.14	10 months	Standby after charging
19	Wando	5.2	PV	Mountainous district	EPS Panels	19.01.14	1 year 2months	Charging
20	Jangsu	2.5	PV	Mountainous district	Container	19.01.15	9 months	Standby after charging
21	Ulsan	46.8	Frequency & peak control	Factory area	Concrete	19.01.21	7 months	Standby after charging
22	Chilgok	3.7	PV	Mountainous district	EPS Panels	19.05.4	2 years 3 months	Standby after charging
23	Jangsu	1.0	PV	Mountainous district	EPS Panels	19.05.26	1 year	Discharging
24	Yesan	1.5	PV	Mountainous district	EPS Panels	19.08.30	1 year 8 months	Standby after charging
25	Pyeongchang	21.0	Wind	Mountainous district	EPS Panels	19.09.24	2 years 8 months	Standby after charging
26	Gunwi	1.5	PV	Mountainous district	EPS Panels	19.09.29	1 year 9months	Discharging
27	Hadong	1.3	PV	Mountainous district	EPS Panels	19.10.21	1 year 3 months	Standby after charging
28	Gimhae	2.2	PV	Champaign	EPS Panels	19.10.27	1 year 6 months	Standby after charging

According to type, a total of 18 ESS fire accidents occurred in ESS linked to photovoltaic power plants, accounting for 65% of the total fires, and in the case of wind power, there were 4 cases. In other words, about two-thirds of fires occurred in the ESS linked to the RE. Considering the fire accident date and operation period of ESS, most fire accidents occurred in ESSs installed in 2017 and 2018. For the accident type, 17 fires occurred while the ESS was on standby after charging. This accident status shows that when the battery is charged fully with a lot of energy and standby before next discharging, it can be vulnerable to thermal runaway and lead to fire accidents.

Yoon (2020) pointed that most ESSs fully charge the battery to maximize profitability before ESS fire accident. In other words, over 95% of the SoC (State of Charge) of the battery is used. Since the Government limited SoC to 80%, ESS fire accidents have significantly decreased. So, harsh application conditions of ESS battery such as over-charging, may have a close relationship with fire accidents.

5. Result

5.1. Black box: Socially constructed ESS technology

ESS fire accidents can be approached as social structural problems. ESS fire accident is not a sudden appearance of a technical failure but a socially constructed technical artifact due to the interaction of RSGs and Social environment. This analysis deals with the social construction of ESS technology, focusing on the interaction of ESS stakeholders (RSGs) with social environment changes, such as government support policies and regulations.

The Korean government provided RE support plans, policies, and research support in an effort to respond to climate change and energy transition. In 2017, the government established Renewable Energy 3020 Implementation Plan for increasing the supply of renewable energy and the growth of the related market. The implementation plan aimed to achieve 10.5% renewable energy power generation by 2022 and 20% by 2030 (MOTIE, 2017). The government provided various policy supports related to ESS to facilitate the supply of renewable energy.

The government strengthened support policies related to ESS to expand RE supply. The importance of ESS has increased because it can supplement limitations in RE operation. ESS can change the electric energy industry structure from ‘production-consumption’ to ‘production-storage-consumption’. Accordingly, electric energy efficiency will rise dramatically, and the national power grid can overcome the limitations of ‘intermittency’ and irregular electric power output of RE generation. Therefore, ESS was expected to play the role of a game-changer in energy transition for the above advantages (Bubbico et al., 2018; Daim et al., 2012; Kear et al., 2012; Schrodgers, 2016). Therefore, the government has carried out small and medium-sized technical demonstration projects of ESS (e.g., Energy Independent Island, Jeju-do Demonstration Complex for ESS). In addition, the Ministry of Knowledge Economy (currently the Ministry of Trade, Industry and Energy, MOTIE) continued ESS pilot projects as R&D with Energy Storage Technology Development and Industrialization Strategy (K-ESS 2020) (MOTIE, 2011).

5.1.1. Social Environment: Changes in Renewable Energy Support Policy

The Korean government utilized the Feed-in Tariff (FIT) and Renewable Portfolio Standard (RPS) to accelerate renewable energy supply. FIT directly provided subsidies to renewable energy power plants that are difficult to invest in the private sector due to high initial investment costs. However, since the government's continuous financial support is limited, the RPS, which allocates the obligation to generate renewable energy to major public power companies, was newly established and utilized in 2012 (Lim and Jo, 2017). RPS makes it mandatory for energy suppliers (over 500MW) to supply a certain percentage of electricity as RE.

RPS issues a Renewable Energy Certificate (REC) to power generation operators for electricity produced by RE. REC is a certificate given to 1MWh of electricity produced by RE and is possible to trade at RPS market. Large energy suppliers need RECs to achieve a mandatory quota of RE power generation. As a result, large energy suppliers were able to meet their quotas using two methods: 1) building their own RE plants and 2) trading RECs from other RE generation operators. REC made a new market for REC trading and brought the following characteristics. Large energy suppliers were able to meet their quotas without having to build new RE plants. The government was able to reduce the direct financial burden for the expansion of RE support policy. However, it was difficult to enter the market in the private sector due to risk factors such as the high installation cost of PV plants or ESS. Therefore, the government gave additional REC weight to the electricity produced by RE plants linked to ESS and made it possible to secure higher profitability than other RE sources (KEA, 2020).

The government's ESS-related support policy changed significantly before and after the provision of REC weight 5.0. At the beginning of ESS support, the government made it mandatory for public institutions to install ESS and provided a special discount rate for industrial electricity costs. However, the number of public institutions is limited, and public corporations, which are electric power suppliers, increase their financial burden due to a special discount rate. In the end, the government provided an additional REC weight of 5.0 to ESS linked to RE power plants to expand ESS installation. As a result, private power generation operators that installed ESS could obtain additional revenue and increase business feasibility through a REC weight of 5.0. For example, the selling price of REC varies by 5.0 times depending on whether ESS is linked to photovoltaic (PV) power generation (KEA, 2016). This can be very attractive in terms of profitability, even considering the high cost of installing ESS. REC weight was changed as follows.

Table 5.1 REC weights by energy source (2019) modified from RPS improvement plan (KEA, 2018)

Source	detailed criteria	Current weight	Revision of weight
Photovoltaic (PV)	less than 100kW	1.2	0.7
	from 100kW	1.0	
	over 3000kw	0.7	
Waste	waste	0.5	0.25
	RDF power generation, gasification plant	1.0	
ESS linked to RE	PV	5.0	4.5 in 2019 → 3.5 in 2020
	Wind	4.5	4.5 in 2019 → 3.5 in 2020

The REC weights for various energy sources vary considerably from 0.7 to 5.0. Unlike other energy sources, provisioning a weight of REC 5.0 for ESS is unusual and problematic in that policy benefits

can be concentrated on specific energy sources. Moreover, concerning such exceptional support from the government, suspicions have been raised that the past administration of Park Geun-Hye was to provide economic incentives to battery manufacturers such as large companies (Lee, 2017b; Jeong, 2018). Jeong (2018) mentioned that battery manufacturers were having difficulties entering the overseas market at that time and needed new demand for already produced batteries.

5.1.2. ESS technology and social context

The ESS support policy utilized the mandatory installation of ESS by public institutions and the special discount rates on RE electricity (MOTIE, 2016a). However, as the expansion of RE increased, the social context changed. Many small PV power plants are connected to the power grid, and it is necessary to balance power supply and demand due to the intermittency problem of RE power generation (Lee, 2014; Jo and Jang, 2019). ESS has an advantage in controlling energy demand and supply through the ability to store energy. Accordingly, the government has provided an intensive support policy for ESS linked to renewable energy since 2017 (MOTIE, 2016b). As mentioned above, the government provides strong economic incentives to ESS such as REC 5.0.

The rapid increase in ESS installations from 2017 can be seen as a result of stakeholders responding to the government's support policy. REC 5.0 was determined through the following process. The government conducted a cost-benefit analysis to calculate the REC weight for the ESS and conducted discussions and public hearings with experts (MOTIE, 2014). The cost-benefit analysis aims to calculate the weight required to secure the government's ESS installation goal and the economic feasibility of private power generation operators. Accordingly, the necessary amount of electricity according to the seasonal power peak pattern and the generation pattern of renewable energy sources by daily period were considered. The government provided REC 5.0 to the ESS in consideration of the analysis results. Due to the provision of REC 5.0 weights, ESSs linked to renewable energy were rapidly installed. ESS installation status by year is as follows.

Table 5.2 ESS installation status from MOTIE (2019)

Year	~'13	'14	'15	'16	'17	'18	Total
Installation	30	47	124	74	268	947	1,490
Battery (MWh)	30	36	145	207	723	3,632	4,773

In particular, while the total number of ESSs installed in 2018 was 947, 461 (48.6%) were PV-related ESSs. This installation status means that the increase in ESS was concentrated in connection with PV. Moreover, among ESSs linked to PV, more than half of ESSs are linked to private power

plants with a scale of 100kw or more and less than 1Mw (KEA, 2018). This situation means that the number of private power generation operators linking small and medium-sized RE power plants with ESSs has increased rapidly. The following is the status of ESS supply according to the size of solar power plants.

Table 5.3 PV-linked ESS installation status modified from KEA (2018)

PV type	PV linked to ESS	2017	2018(Jan to Oct)
Under 100 kW	Number of Plant	13	195
	Capacity of ESS	3 MWh	51 MWh
100 kW to under 1MW	Number of Plant	31	299
	Capacity of ESS	60 MWh	679 MWh
Over 1MW	Number of Plant	14	105
	Capacity of ESS	78 MWh	861 MWh
Sum	Number of Plant	58	599
	Capacity of ESS	141 MWh	1508 MWh

As the number of private power generation operators increased, the demand for ESS also increased sharply. Moreover, many companies that manufacture ESS-related products entered the ESS industry. ESS industry market has grown rapidly due to the increase in demand for batteries and electric control devices, which are the main internal components of ESS (Lee, 2018; Oh, 2019).

5.1.3. Relevant Social groups of ESS technology

ESS production and sales have the following characteristics (Hong, 2017). In ESS, batteries and PCS are the main products, and the entire system's efficiency depends on the quality of the PCS. Batteries account for the largest portion of ESS production cost. Due to the high price of batteries, private power generation operators may have difficulties in deciding to install ESS. Therefore, in the initial stage of activation of the ESS market, it is dependent on the government's support policies and subsidies.

According to the major internal components of ESS, each field has characteristics that are affected by the company's technology and financial scale (Hong, 2017). The battery manufacturing field mainly consists of large-scale finished product manufacturers based on lithium-ion battery technology that requires advanced technology. On the contrary, in the electric control field that controls the battery charge/discharge inside the ESS, large companies and many small and medium-sized companies are participating. Many companies have been engaged in other fields because PCS for ESS can be used with slightly improved existing electrical control products. For example, companies dealing with

control devices such as inverters have shifted to PCS manufacturing. Some electrical control products of ESS were not designed exclusively for ESS, but were applied to ESS through slight modifications, which also affected the occurrence of function problems. In addition, there are EPC companies such as system integrators and ESS project developers that assemble the system. However, most PCS companies are also playing the role of EPC such as, planning and installing ESS projects.

Stakeholders related to ESS technology can be briefly divided into those who configure the system and utilize it. The system configuration can be mainly divided into battery and electric control fields, and they are working together to design, develop, and produce ESS. The side that utilizes the system consists of the government and the private business sector. The government is using ESS as a mean to achieve the policy goal of expanding RE. Users are primarily small-scale renewable energy generation operators. And these are relevant social groups that are connected to configure or utilize ESS. The following figure shows the connection structure of these social groups.

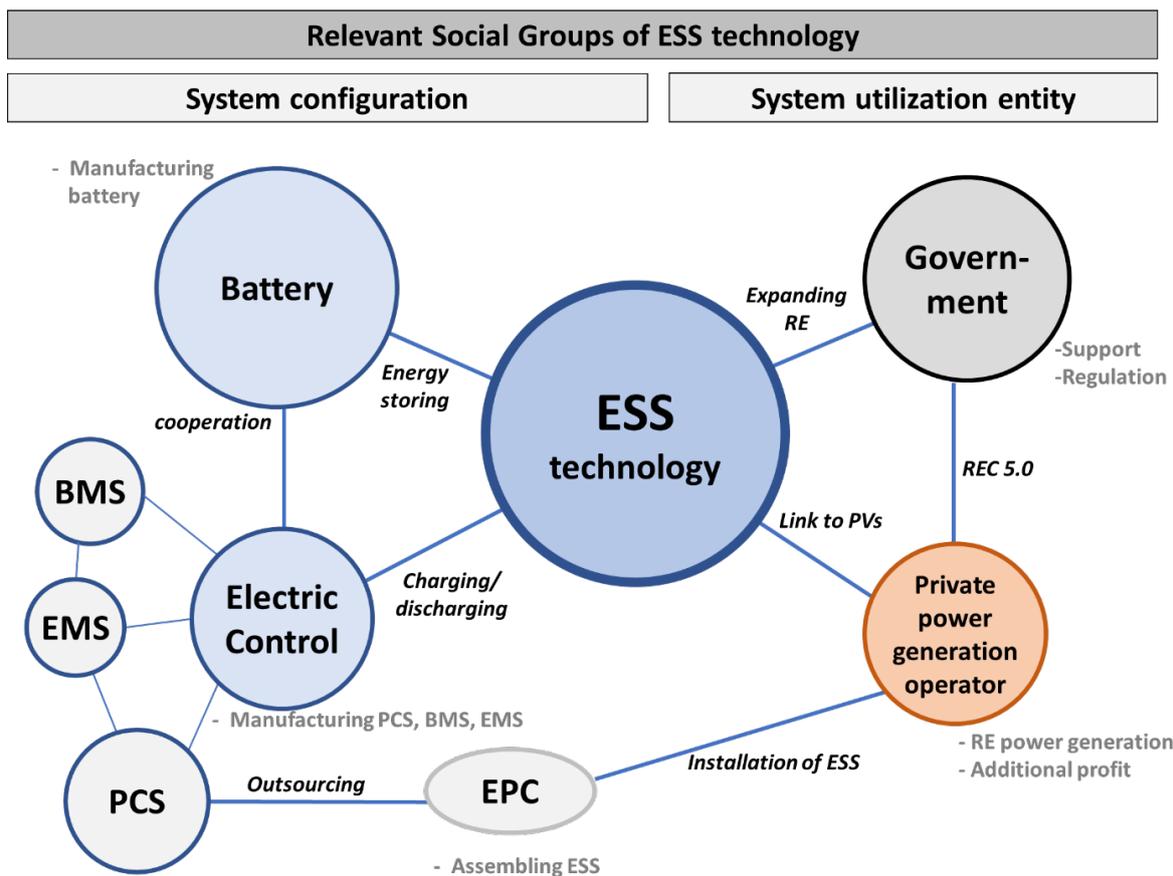


Figure 5.1 ESS Relevant Social Groups, Source: author

As can be seen from the figure above, RSGs are interacting with each other around ESS technology. The government implemented support policies and regulations to expand RE supply. Accordingly,

private power generation operators are trying to install ESS to get additional profit through PV power generation plants. Battery and electric control product manufacturers responded to ESS demand and sharply increased production and supply of major components of ESS. Through these interactions, ESS technology began to be socially constructed by the RSGs and their interactions.

5.1.4. Interactions of Social environment and Relevant Social Groups

ESS technology is socially constructed by the interaction of RSGs. Through this, the adopted ESS technology becomes a Black box perceived as a scientific fact and utilized without any doubt. Therefore, the interaction of RSGs with social environments such as government support and regulation are analyzed.

Focusing on the government's economic incentives for ESS, private power generation operators, battery, and electric control manufacturers had various interactions. Focusing on the government's economic incentives for ESS, private power generation operators, battery, and electric control manufacturers had multiple interactions. For example, private power generation operators utilized ESS to charge and sell as much electricity as possible for additional REC revenue. In addition, major ESS component manufacturers chose to increase the production of batteries and PCSs rapidly. Thus, they made a rational choice to pursue the maximum economic benefit.

Two significant factors influenced the behavioral decisions in achieving the goals of social groups related to ESS. First, in the private business sector, it is possible to understand the changes in the social environment in which the installation of ESS is rapidly increasing by analyzing the profitability of power generation operators. Second, there are interactions in which the manufacturers respond to regulatory policies for ESS production. Safety-related regulations enable manufacturers to make legitimate choices to pursue maximum profits within the boundary of regulations. The social environment, such as government support policies and safety regulations, influences the interaction of relevant social groups to achieve their goals.

1) Increasing ESS demand from private power generation operators

Socially constructed ESS technology begins to be widely utilized. ESS technology is adopted and used as a scientific fact by private power generation operators. In particular, the strong driving factor of high profitability accelerated the expansion of ESS installation further. After all, ESS technology can become a widely used Black box by many RSGs without question or doubt. The government's strong ESS support policy called REC 5.0 can significantly impact making socially constructed ESS technology a Black box. Therefore, social groups such as private power generation operators simulate the profitability obtained through ESS technology.

Through ESS profitability simulation, this part examines the impact on the demand of private power generation operators. In the private business sector, the installation decision for ESS is mainly based on profitability. A REC weight of 5.0 made for a rapid expansion of ESS installations by private power generation operators. Accordingly, ESS profitability simulation is conducted, and how the economic incentive of REC 5.0 worked for private power generation operators is reviewed. In addition, a profitability simulation was conducted based on 2018, when most ESS was installed, to understand why private power generation operators installed ESS.

Unlike the government's attempt to maximize social good by considering social costs such as environmental impact through cost-benefit analysis, the profitability simulation of private operators considers only the maximum economic benefit. The profit generation structure of PV power generation is to transmit the electricity produced during the daylight hours to the power grid and receive the electricity sales amount. If the ESS is linked to PV plant, a power storage process can be added between the power generation and transmission process. The electricity sales price is the sum of the System Marginal Price (SMP) and the REC sales price of electricity supplied to the power grid (MOTIE, 2011). When the electricity charged in the ESS is sold, it brings additional revenue by multiplying the REC price by a weight of 5.0.

For the profitability simulation, power generation facility installation cost, power generation unit price, power generation amount, electricity market price, interest rate, ESS efficiency, Etc. were investigated and set from the most conservative point of view (Lee and Kim, 2015; Kang et al., 2018). Profitability simulation of PV power plant was conducted. For the basic conditions of this simulation, the default settings in Table 5.4 were applied. As a result of conducting a profitability simulation in the same PV power plant depending on whether ESS is linked or not, the private power generation operator got an additional profit of about 1.8 times with PV linked to ESS for one month.

However, simply generating additional revenue does not sufficiently explain the sharp increase in ESS demand in the private business sector. Another reason for this increase in demand is that the REC weight of ESS is scheduled to decrease gradually. The government announced that in 2020, the weight of PV-linked ESS will be reduced from 5.0 to 3.5 (KEA, 2018). The reduction in REC weight is because, as technology advances and the market size increases, ESS installation costs decrease and price competitiveness increases (Noh, 2019). From the point of view of a private power generation operator, the gradual decrease in the REC weight of ESS means a decrease in expected revenue. In the end, the reduction of the REC weight 5.0 to 3.5 was a kind of deadline, which forced private power generation operators to install ESS, and private power generation operators carried out ESS installation vigorously in 2018.

A profitability simulation was performed considering these changes in the social environment. The simulation reflects the REC weight (5.0 vs. 3.5) reduction scenario with the initial installation cost, bank loan, and interest. The profitability simulation examined the difference between the period in

which the total amount of power generation proceeds was reimbursed for all expenses put into the business and the net profit. The conditions for investment and recovery costs for the simulation are as follows.

Table 5.4 Condition of profitability of PV linked to ESS

Default setting		Costs Assumptions	
PV capacity (Kw/H)	1,000	Initial installation cost (KRW): PV	2,000,000,000
Average Daily Generation (Hour)	3.5	Initial installation cost (KRW): ESS	2,500,000,000
		Total installation cost	4,500,000,000
ESS Capacity (Kw)	3,000	Owner's equity ratio (%)	20%
Battery efficiency (%)	74%	Equity capital investment amount	900,000,000
Charge/discharge loss rate(%)	30%	Loan	3,600,000,000
SMP Price (Won/kw)	80	Loan interest rate (%)	4%
REC Price (Won/kw)	100		
REC weight for PVs	1.0		
REC weight for PVs link to ESS	5.0		

As a result, the payback period for each scenario approaches five years earlier in Scenario 1 than in Scenario 2. And in each REC weight scenario, from the moment the cost repayment is completed, all electricity sales revenue (SMP+REC) is the profit of the private operator. Thus, private power generation operators could obtain relatively more economic incentives to install the ESS as quickly as possible while the government provided the REC weight of 5.0. The simulation result is as follows.

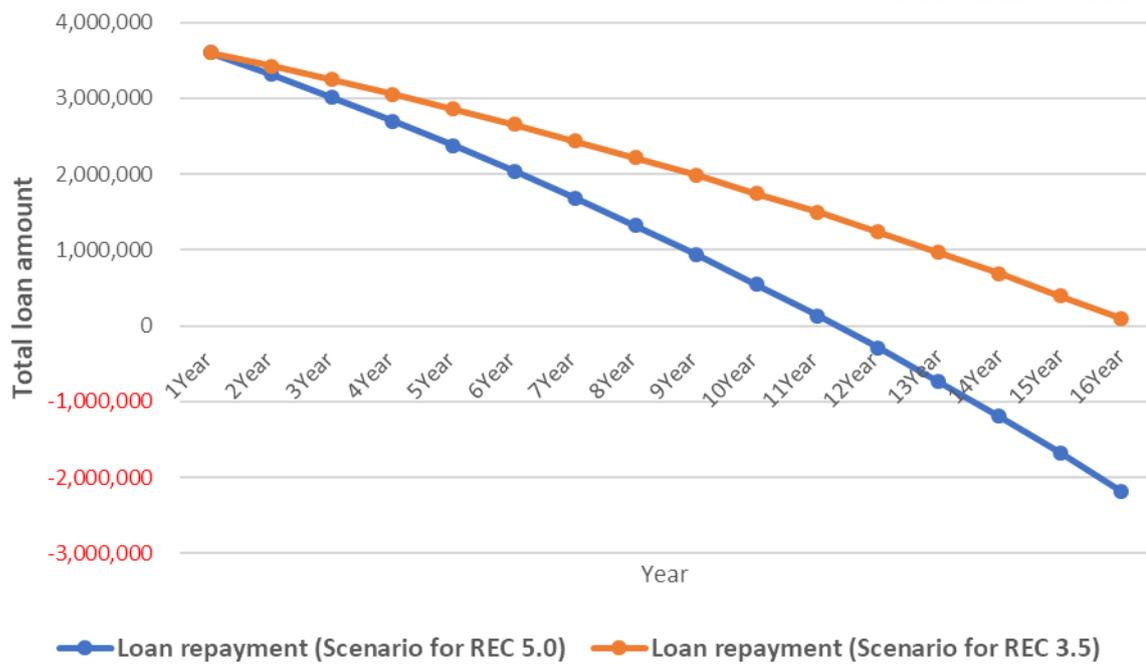


Figure 5.2 Profitability simulation according to REC weight (5.0 vs. 3.5)

Private power generation operators focused on how much profit they could get rather than a technical understanding of ESS. Otherwise, it would have been challenging to expand the ESS in a short period of one to two years. Moreover, the ESS technology, which the government strongly supports, was accepted as a scientific fact that can be used without doubts or questions. As a result, there was a tendency for the installation of ESS to expand rapidly as can be seen in Tables 9 and 10.

2) Safety regulations for relevant social group (ESS component manufacturer)

In line with the demand for ESS, the number of component manufacturers for supply has also increased. According to Hong (2017), small and medium-sized companies that make electrical and electronic control-related products such as inverters have entered the market with ESS as a new business model. For example, companies that were making electric control circuits for solar power generation changed the design of existing products for ESS and started selling improved products. Companies that are even slightly related to ESS have entered the market by setting ESS as a new business model.

In the increasing interest in ESS by various social groups and expanding the market, the consensus among major social groups has begun. Various standards for ESS technology have been established due to flexible interpretation and negotiation among these RSGs. In 2016, 'KS C 8548', universal terms for battery energy storage system(B-ESS), tried to unify related technical terms. Moreover, standards of private organizations related to ESS technology were established in 2019. Private organizations include major manufacturers of ESS components. The standards included general information about the internal

functions of an ESS and internal components. There are safety considerations and requirements in the standard as well. For example, 'KS C IEC/TS62933-5-1' defines general items for ESS safety and reliability.

However, such rapid market growth can have side effects. The government's economic support-oriented policies to achieve the ESS installation goal have not been sufficiently tested to commercialize ESS technology. Even the insufficient regulatory environment that cannot keep up with new technologies can act as a bigger obstacle to securing safety. In response, Jang (2020) pointed out that the electric control field lacked professional human resources to respond to the sudden increase in ESS installation demand, leading to ESS installation errors. He mentioned that the diffusion period was very short compared to the amount of ESS installed, and the lack of period for technology commercialization and insufficient safety regulations related to ESS. In response to this lack of regulatory environment, the government suggested strengthening Korea Certification (KC), establishing Korea Standard (KS), and private sector standards as ESS fire safety measures (MOTIE, 2019).

As mentioned above, only the private organization standards existed as guidelines for ESS design and development. And since the organizations that set standards for the private sector are mainly composed of ESS-related companies, it isn't easy to make tight regulations to ensure safety. In addition, the official government regulations also did not secure specific details in securing safety. For example, 'Inspection guidelines for energy storage system (SPS-KESG-VI-M-14-7286)' of Korea Electrical Safety Corporation and 'Criteria for Electrical Equipment Technical Standards' of Korea Electric Association didn't have specific details on the fire extinguishing equipment, smoke and fire detection, fire division setting, and thermal runaway prevention. The domestic safety standard reveals quite insufficient parts even when compared with the safety-related standards with NFPA 855, the fire safety standard of the United States (Noh, 2019).

Before the ESS fire, there was no need to obtain certification because ESS was not subject to safety management obligations. This is because the final assembly product, ESS, only needs to pass the minimum industrial safety standard and private organization standard only for internal main products such as batteries and electric control components (MOTIE, 2019). In other words, regardless of the technology and safety of the finished ESS product, it can be sold only if the operation of the ESS is confirmed using certified batteries and electric and electronic control products. Since the price of the battery occupies a large portion of the main ESS products, adding safety functions beyond the requirement of the legal regulations for electric control parts (PCS, BMS, and EMS) can be an economical concern for manufacturers. Accordingly, some of the companies related to ESS were able to easily obtain legitimacy within the boundary of insufficient regulations, add minimal safety functions, and pursue more profits. Because the goal of ESS manufacturer is to maximize profit.

5.1.5. Summary

The government provided various support policies such as special electricity discount rates and REC Multiplier to expand domestic ESS installation. Based on this policy, ESS installations increased sharply to 268 in 2017 and 947 in 2018 (MOTIE, 2019). However, as fire accidents continue to occur in ESS and become a social issue, the government's official investigation into the cause of the fire was conducted in the ESS. The official investigation committee pointed out that the fire occurred because the ESS failed to properly manage technical defects at the level of an integrated product (MOTIE, 2019; MOTIE, 2020). However, as mentioned above, ESS technology was socially constructed while being influenced by relevant social groups and social environments. Moreover, the government's official investigation results did not fully consider the impact of social factors.

The government wanted to expand ESS installation to achieve the goal of expanding RE (MOTIE, 2017). ESS users, power generation operators wanted to obtain higher profits rather than the existing RE power generation business. ESS components manufacturers wanted to gain economic profits from increased product sales. Furthermore, concerning the rapid expansion of ESS installation, several relevant social groups negotiated and reached a consensus for socially constructed ESS technology. As a result, various private organization standards were established, and the installation of ESS increased rapidly.

The government's economic incentives and insufficient safety regulations constituted Social environment. Moreover, ESS stakeholders have become RSGs that manufacturers, installs, and utilizes ESS. Therefore, social groups interacted while pursuing the interests of each group in Social environment, and RSGs on ESS adopted the final form of ESS. In the end, the ESS was constructed in the negotiation process to narrow the interests and gaps of related social groups with the change of social context, rather than just developing along the efficient trajectory of technology. Moreover, ESS, a socially constructed technological product, was perceived as a 'Black box' used by users without any doubt as a means rather than concern about internal technical complexity.

Through various literature analysis and a profitability simulation, the process of social construction of ESS technology was reviewed. However, due to the limitations of the literature, it was not possible to provide a sufficient explanation for the conflict and negotiation process due to the interests among the social groups concerned. Therefore, in the next chapter 5.2 and 5.3, the analysis of the interview data is carried out using the main concepts of the accident approach models with Semantic Network Analysis and Thematic Analysis.

5.2. Exploring Significant issues on ESS fire accidents

An exploratory approach is carried out to find various interactions that occurred with various RSGs and ESS technology. Semantic Network analysis (SNA) was conducted based on various ESS industry experts' experiential data. SNA was performed on qualitative data to supplement the limitations of the subjective interpretation by the researcher. SNA explores structures based on shared meaning rather than simply the connection of keywords (Doerfel and Barnett, 2006). Therefore, the analysis method is meaningful in that it is possible to comprehensively explore the thoughts, cognitive structures, and schema inside human beings through the language of the interviewees (Chung et al., 2015). The appearance of 'theme' and 'code' derived from TA is validated in the language network. This chapter deals with ESS technology, causes of fire accidents, and various other issues in the semantic network of qualitative data.

An overview of the qualitative data is as follows. A total of 24 industry workers were interviewed regarding ESS fire accidents. The interviewees consisted of battery experts (7), electrical and electronic control (6), ESS installation and construction (5), fire victims (3), and others (3, public companies, fire facilities, Etc.). The main questions consisted of the industry's perceptions of the causes, risks, and overall ESS market conditions of ESS fire accidents. All interview data were textualized, and the relationship between interview keywords was reviewed through NetMiner, a language network program, to analyze the semantic relationship between the languages.

This analysis explored the meaning of ESS fire accidents recognized by relevant social groups of ESS through SNA. In this study, NetMiner4.3.0.b, a language network program, was used for network analysis. Data analysis went through three steps: data input, data preprocessing, and network analysis. In the data input step, the scripts of the interviewees were converted into text. The program can refine words by building a dictionary of synonyms, designators, and negatives. In this process, words with similar meanings went through a process of consolidation (SMEs, small businesses, small companies, Etc.). In addition, 'ESS', 'fire' and 'battery' were excluded from the analysis because their appearance frequency was too high compared to other keywords, and the language network could be biased towards specific words.

The data preprocessing step is the process of extracting meaningful relationships from the entire semantic network. In this step, nodes and links that have little relevance to the interview questions and whose mutual influence are unknown were removed. Through this, it was converted from the two-mode matrix (document-words) to the 1-mode matrix(word-words). In order to check the connections between major nodes and their meanings in colloquial answers to various questions, the data was processed as 'undirected'.

Network analysis can be performed based on the co-occurrence of major nodes. However, in the corresponding SNA, important nodes and links were extracted using cosine similarity. The cosine

similarity is calculated for the analysis target, that is, the vectorized interview answers. It is vectorized into 1 and 0 according to the appearance of nodes extracted from the interview answers and calculated according to the following equation in consideration of the appearance of each node. The cosine similarity of node(vector)s is closer to 1, the higher cosine similarity between the two vectors, which can represent an important meaning in the network compared to other vectors. The cosine similarity is derived through the following formula.

$$\text{Cosine Similarity} = \frac{\sum_{k=1}^n C_{ik} C_{jk}}{\sqrt{\sum_{k=1}^n C_{ik}^2} \sqrt{\sum_{k=1}^n C_{jk}^2}}$$

There are studies using cosine similarity to analyze unstructured text data (Dam and Kaufmann, 2008; Kim and Lee, 2014; Patra et al., 2012). The data analyzed in this study is also unstructured data and has the following characteristics. There were respondents from various fields such as batteries, electric control manufacturers, and fire victims, and the amount and logical structure of the answers were very different for each respondent. For example, the same amount of interview answers cannot be given to a specific question, and the longer the answer, the more repetition of a specific word. In this case, the frequency of occurrence of the specific word is affected by the length of each interview, and the frequency of co-occurrence with other words is also increased. However, just because the length of the answers to the interview questions is long and frequent does not mean that it is important and that the length of the answers to the interview questions is short or small does not mean that it is meaningless. Because of this limitation, cosine similarity is used. Rather than the absolute frequency of co-occurrence of nodes, the importance of nodes is determined through normalized weights between major nodes. Through this, it is possible to relatively reduce the distortion of data according to the length of answers and to derive the main meaning (Dam and Kaufmann, 2008).

The next step is to analyze the structural characteristics of the semantic network. Centrality is a measure of discriminating nodes that represent meaning in the network. SNA analyzed the meaning of major nodes based on degree centrality and betweenness centrality in this chapter. Degree centrality is a measure of the degree to which one node is connected to other nodes. It means the ratio $((1 \cdot a/N) \cdot 100)$ that other nodes (a) connected to a certain node (1) occupy among the nodes (A) of the entire network. That is, a node with high degree centrality plays the role of a local hub in the entire network. Betweenness centrality indicates the degree to which a particular node plays a mediating role when different words create meaning through connections. A node with high betweenness centrality acts as a

link through which the node generates various meanings in the entire network (Park et al., 2017). A node with a high betweenness centrality forms a frame for the overall perception of a specific issue in the entire network by interconnecting other nodes.

Finally, community-betweenness analysis was conducted. In general, community structure refers to a set of relatively densely connected nodes within a network, and by using this, the structural meaning of the entire language network can be found. Community analysis classifies links within sub communities of the entire network so that there are more links between communities. That is, similar nodes are grouped together to form a single community. This is useful for identifying nodes with similar meanings in the network and finding specific topics. Community analysis was performed using the Girvan-Newman algorithm (Girvan and Newman, 2002). This repeats the process of removing and re-clustering the link with the greatest betweenness centrality within the network. In this process, several cluster models are derived. Modularity value is used to select an excellent community model, and community networks of 3.5 or higher can be used as an excellent model (Cyram, 2017). Through this analysis process, respondents' perceptions, and main meanings of the ESS market, policies, and fires revealed in the interview are analyzed.

5.2.1. Characteristics of ESS perceived by relevant social groups

A total of 3,332 words appeared in the interview data, and a total of 64 major nodes were derived through the pre-processing process. Major nodes are arranged in order according to their frequency of occurrence. The top 30 major nodes are as follows.

Table 5.5 Top 30 nodes of entire participant

Rank	Word	Freq.	Rank	Word	Freq.	Rank	Word	Freq.
1	Cell	448	11	Energy	216	21	Circuit	176
2	PV	385	12	Occurrence	215	22	PCS	174
3	Company	365	13	Control	213	23	Condition	171
4	Market	323	14	Design	213	24	Price	168
5	Government	304	15	Risk	206	25	Development	165
6	Test	282	16	Technology	206	26	Charging	163
7	Revenue	275	17	Certification	205	27	Power generation operator	162
8	Samsung	271	18	Field	198	28	Policy	155
9	Safety	263	19	Heat	187	29	BMS	153
10	Standard	217	20	REC	181	30	Specification	139

Major nodes are 'Cell (1st)', 'PVs (2nd)', 'Company (3rd)', 'Market (4th)', 'Government (5th)', 'Test (6th)', 'Revenue (7th)' appeared in the order. These are the nodes about the overall perception of ESS

fire and the market structure. In addition, there are nodes related to various issues such as causes of fire and conditions for fire occurrence. However, it is difficult to provide a sufficient explanation simply by the frequency of occurrence.

Therefore, centrality analysis and community analysis of major nodes were conducted. Centrality analysis calculated degree centrality and betweenness centrality. And through community analysis, cohesion of major nodes was classified by group. The table below shows the centrality of major nodes.

Table 5.6 Centrality of Entire participant

Rank	Word(community)	Degree	Word(community)	Between
1	PV (3)	0.234	Field (3)	0.527
2	Revenue (3)	0.203	Major (5)	0.454
3	Power generation operator (3)	0.172	Restriction (4)	0.401
4	Policy (3)	0.172	Experience (5)	0.396
5	Public power Inc. (3)	0.125	PV (3)	0.296
6	RE (3)	0.125	Provision (3)	0.263
7	Provision (3)	0.094	Measure (4)	0.228
8	Power plant (3)	0.094	Energy (3)	0.177
9	REC (3)	0.094	Power generation operator (3)	0.164
10	Field (3)	0.078	Safety (6)	0.149
11	Limit (4)	0.078	Revenue (3)	0.148
12	Measure (4)	0.078	Company (2)	0.146
13	Energy (3)	0.078	Installation (3)	0.136
14	Safety (6)	0.078	PCS (1)	0.121
15	Installation (3)	0.078	Control (7)	0.107
16	Charging & discharging (4)	0.078	Occurrence (7)	0.083
17	Charging (4)	0.078	Charging & discharging (4)	0.071
18	EPC (2)	0.078	Equipment (3)	0.062
19	Large company (2)	0.078	Samsung (1)	0.062
20	Construction work (3)	0.078	Charging (4)	0.048
21	Government (3)	0.078	EPC (2)	0.044
22	Loss (2)	0.078	Air conditioner (7)	0.043
23	Major (5)	0.063	Policy (3)	0.039
24	control(7)	0.063	Public power Inc. (3)	0.037
25	Occurrence (7)	0.063	RE (3)	0.037
26	Condition (4)	0.063	Heat (7)	0.035
27	Profit (3)	0.063	Large company (2)	0.033
28	Invest (3)	0.063	Condition (4)	0.032
29	Support (2)	0.063	Secure (6)	0.031
30	Market (3)	0.063	Technology (7)	0.031

Degree centrality refers to the degree of connection with neighboring nodes, which means the importance of the node in network. 'PVs' rank first in degree centrality. And the centrality of 'RE' (degree (d):6th, betweenness (b): 24th), 'Policy' (d:4, b:23), and 'REC weight' (d:7, b:36) are ranked in high order. High degree centrality can be seen as leading the flow of meaning across the network. In other words, the semantic network of all interviewees was composed centered on 'PVs' and 'REC weights' related to 'RE'. And, as mentioned in TA, these nodes can be interpreted as a major social context that affects ESS technology.

What is unusual is the nodes with high betweenness centrality. 'Fields' and 'Major' have the highest mediation centrality. This means that other major nodes are connected to each other centering on 'Field' and 'Major'. Moreover, these nodes play a major role in forming the frame of the respondents' perceptions about ESS and fire accidents appearing in the interview. The following figure shows the semantic network of all interviewees.

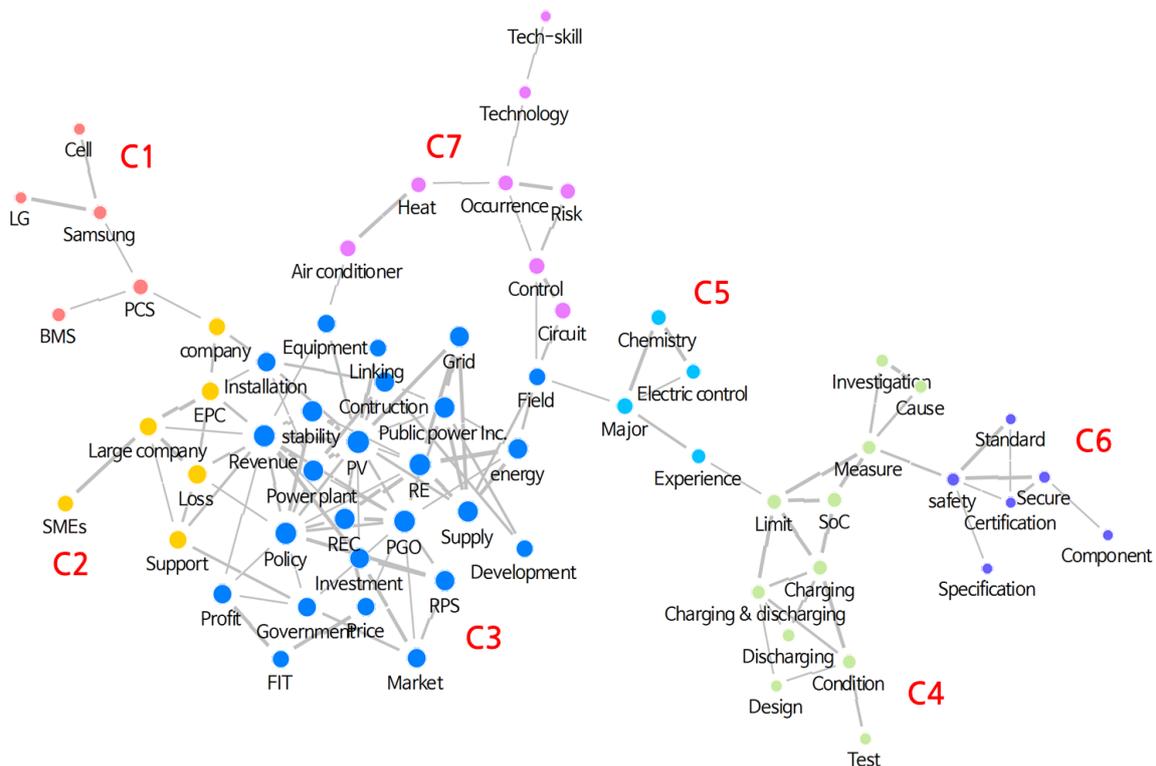


Figure 5.3 Semantic network result of Entire participant with Community analysis on ESS organization (Modularity 4.816, over 3.75)

Through community analysis, nodes with high cohesion were classified by the community. The modularity value of community analysis is 4.816, which means that the community structure is optimized. Among the communities, 'PVs', 'RE' and 'Policy' in C3 are connected within the same community. As mentioned in Chapter 5.2, it was confirmed that nodes that mean ESS support policies,

which are social contexts, are linked in the same community of the entire semantic network. In addition, ‘Government (C1)’ shows the structure connected to ‘Support (C2)’ and ‘Revenue (C3)’. This can be interpreted as ‘Investment (C3)’ by private power generation operators to obtain profits.

Characteristics constituting the ESS organization can be found through C1 and C2. C2 has 'Large company' and 'SMEs.' C1 has 'Cell' and 'PCS.' This means that 'Company (C2)' belonging to each field for manufacturing ESS is directly connected with C1. In the end, each community's characteristics and connection structure means that cooperation of the ESS organization exists. These communities are connected to a node called 'Profit' in C3. This shows that the ESS organization derived from TA has a technology-profit-based alliance of relevant social groups. 'Field' (C3) has the highest betweenness centrality as mentioned above and connects different communities. Especially, C5 shows that the majors of ESS-related workers consist of chemistry and electrical control. Moreover, C5 is connected to the 'Field' of C3. It indicates that related social groups in the network of all respondents distinguish related social groups based on two Majors. Furthermore, 'Field' is also linked to the causes of fire in C7. In the end, it indicates recognition of ESS, products, and fire causes centering on the 'Field' of C3.

Beyond that, C7 is a community on fire risk management. Nodes such as ‘Circuit’, ‘Control’, and ‘Air conditioner’ are connected. All respondents perceive that thermal management of ESS is necessary for fire prevention. C4 has nodes such as ‘Charge’, ‘Discharge’, ‘SoC’, ‘Test’, and ‘Cause’. C4 means the awareness of battery abuse that affects the battery fire risk. In C6, nodes such as 'Safe', 'Standard', and 'Authentication' are connected. C6 means the regulatory environment for fire prevention. In the end, through the connection structure of C4 and C6, Respondents recognize that C4 needs C6 regulation on battery abuse. It can be confirmed that the issues of the insufficient regulatory environment.

To summarize, the social context was confirmed through the nodes of C3 (REC weight, support policy, PV). A lack of regulatory environment emerges through C6. C5 indicates the division of groups according to Majors. Moreover, C2 means the existence of power relation between SMEs and large companies, and C1 shows a tight coupling between internal products (battery and electric control parts) that produce ESS. The fire risk of the ESS was shown in the battery risk in C4 and the fire cause management in C7. It is meaningful that the semantic network can confirm the significant issues, such as social context, the structure of alliance, and battery fire risk.

The connection structure of nodes that appear through the semantic network of all respondents represents various issues related to ESS technology and fire accidents. In particular, the nodes of 'Major' and ‘Field’ are mediating critical nodes in the entire network. There is a distinction between 'chemistry' and 'electric control' groups according to fields and majors, but there was a limit to grasping detailed contents (e.g., the difference in perception). It is necessary to examine differences in perceptions of ESS technology and fire accidents through semantic networks for each relevant social group.

5.2.2. Issues of ESS technology and fire causes by relevant social groups

Relevant social groups using ESS technology were divided into three areas and data pre-processing was carried out. The frequency of major nodes was confirmed by classifying the entire interview data by social group. The nodes most frequently appearing by groups are as follows.

Table 5.7 Top 10 nodes of each relevant social group

Rank	Battery		Electric control		Fire victim	
	Word	Freq.	Word	Freq.	Word	Freq.
1	Cell	286	Cell	109	Company	89
2	Test	149	Risk	103	PVs	38
3	Certification	148	Control	102	Installation	38
4	Samsung	146	Safety	102	Heat	29
5	Company	130	Test	94	REC	29
6	Standard	124	Company	93	Revenue	26
7	Circuit	124	Market	81	Charging	25
8	Li-ion	116	Specification	75	Price	24
9	EV	113	Samsung	72	PCS	24
10	Government	113	Standard	71	Cell	23

The nodes of the interviewees engaged in the battery field were derived. A total of 1,860 keywords appeared, and 76 major nodes were extracted through the frequency of occurrence (more than 18 times, top 5%) through data preprocessing. Based on the frequency of occurrence of major nodes, the key keywords are 'Cell (1st place)', 'Test (2nd place)', 'Certification (3rd place)', Samsung (4th place), 'Company (5th place)', 'Standard (6th place)' followed by 'Circuit (7th place)'. The battery 'Cell', which is pointed out as the cause of ESS fires, appeared frequently. In addition, 'Test' and 'Certification' to prevent fire, 'Businesses' that produce batteries, and 'Circuit' for battery control also show a high frequency of occurrence.

A total of 1261 nodes appeared in the field of electrical control. A total of 60 core nodes were extracted based on the frequency of appearance (more than 14 times, top 5%). 'Cell (1st place)', 'Risk (2nd place)', 'Control (3rd place)', 'Safety (4th place)', 'Test (5th place)', 'Specification (8th place)' and 'standard' (10th)' and so on are the top 10 nodes. In this field, control of battery 'Cell' and 'Standard' for safety are mainly emerging.

A total of 499 nodes appeared in the fire victim interview. The final 43 major nodes were selected through a pre-processing process based on the frequency of appearance (7 times, more than the top 5%). 'Company (1st place)', 'PVs (2nd place)', and 'REC (5th place)' appeared frequently. This indicates that fire victims are private power generation operators who use ESS linked to 'PVs' and seek profit through 'REC' weights.

There is a peculiarity when comparing nodes with high frequency of appearance in three fields. In the two fields of battery and electric control, 'Cell' is ranked first, but the mode ranked 10 for Fire

victim. It can be assumed that fire victims lack awareness of the dangers of battery fires, unlike batteries and electric control fields. However, the frequency of appearance of major nodes in each field is insufficient to explain the relationship and meaning of the major nodes.

1) Centrality analysis by relevant social group

Nodes with a high degree centrality in **the battery field** are related to the charging and discharging of batteries. 'SoC (degree: 3rd place)', 'Harshness (d:9th place)', and 'Heat (d: 10th place)' were found to be important in the network as causes of fires. Betweenness centrality was high in 'Safety (between: 1st)', 'Occurrence (b: 2nd)', and 'Cell (b: 6th)'. After all, the battery field recognizes importance of the battery fire risk caused.

The main nodes in **the field of electrical control** are 'Control (d:2, b:2)', 'Safety (d:4, b:1)', and 'Occurrence (d:3, b:5)'. It is recognized that the failure of ESS control causes a fire. Unusually, the perception of battery abuse (harshness of ESS operation), which the battery field recognized as an important cause of fire, is not revealed in electric control field. This means that the details of the perception of battery(cell) fire risk may be different depending on the two major fields.

Fire victims perceive 'Price (d:2, b:9)' and 'REC (d:3, b:11)' as important nodes. The fire victims were private power generation operators. Therefore, it is important to pursue economic profit by selling electricity through ESS. Regarding centrality betweenness, 'SoC (b: first place)' and 'Loss (b: sixth place)' were found to be high. This indicates that major nodes constitute the frame of network for economic 'Loss' caused by fire accidents. After ESS fire accidents, the government imposed SoC restrictions (under 85%) (MOTIE, 2020). Therefore, fire victims were aware of ESS fire accidents focusing on the economic 'loss' rather than the cause of the fire.

In summary, there are significant differences among the major nodes in each field. The battery field was aware of the battery fire risk itself, while the electrical control field focused on controlling the battery fire risk. Fire victims perceive the fire risk inherent in ESS as an economic loss rather than itself.

The difference between battery and electrical control is unusual. This difference may be a characteristic of technological expertise, or it may be a result of cultural indifference to each other. However, the results of network analysis alone are difficult to conclude on this inference. The centrality analysis values for each field are as the following table.

Table 5.8 Centrality analysis of RSGs

Rank	Battery				Electric Control				Fire Victim			
	Word	Degree	Word	Between	Word	Degree	Word	Between	Word	Degree	Word	Between
1	Charging	0.155	safety	0.204	Performance	0.22	Safety	0.176	Company	0.286	SoC	0.512
2	limit	0.141	Occurrence	0.139	Control	0.186	Control	0.151	Price	0.19	Risk	0.511
3	SoC	0.127	chemistry	0.123	Occurrence	0.186	Performance	0.143	REC	0.19	Discharging	0.508
4	RE	0.127	Technology	0.121	Safety	0.169	Cause	0.122	Installation	0.19	Charging	0.502
5	Occurrence	0.127	Control	0.115	Cause	0.169	Occurrence	0.12	Inspection	0.167	Company	0.497
6	design	0.127	cell	0.113	Circuit	0.169	Circuit	0.098	Occurrence	0.167	Loss	0.46
7	Charging & discharging	0.127	Air conditioner	0.109	Technology	0.169	Price	0.082	Amount	0.143	Unit cost	0.328
8	Condition	0.113	Investigation	0.107	Risk	0.153	Standard	0.077	PCS	0.143	Safety	0.105
9	Harshness	0.113	Condition	0.091	Price	0.136	Field	0.073	Control	0.143	Price	0.098
10	Heat	0.113	Test	0.081	Field	0.136	Term	0.068	Safety	0.143	Government	0.079
11	EV	0.113	Secure	0.08	Voltage	0.136	Risk	0.067	Technology	0.143	REC	0.075
12	Internal	0.113	Policy	0.076	China	0.119	Government	0.067	Unit cost	0.119	Internal	0.075
13	Experience	0.113	Field	0.072	Standard	0.102	Technology	0.064	Equipment	0.119	Amount	0.067
14	Cell	0.099	Specification	0.067	Design	0.102	Design	0.064	Long period	0.119	Occurrence	0.065
15	Field	0.099	PCS	0.066	Company	0.102	Company	0.051	EPC	0.119	Control	0.059
16	Secure	0.099	Cause	0.065	Term	0.085	Voltage	0.049	Expertise	0.119	Samsung	0.049
17	Measure	0.099	PGO(Power generation operator)	0.064	Site	0.085	Site	0.038	Samsung	0.119	Expertise	0.045
18	Certification	0.099	PVs	0.062	Enterprise	0.085	EMS	0.038	Management	0.119	Installation	0.036
19	Safety	0.085	Restriction	0.061	Samsung	0.085	Enterprise	0.034	Contact	0.119	PCS	0.032
20	Samsung	0.085	Company	0.06	Management	0.085	REC	0.034	Internal	0.119	Equipment	0.02

There is a perception that a fire, that is, thermal runaway, may occur if heat management generated during battery charging and discharging fails. It can be confirmed in the network that the continuous damage caused by the battery abusing can be a fire cause. Second, the distinction between chemical and electrical control is shown in that C1's 'Chemistry' and C3's 'Electrical control' are located in different communities. C1 includes 'Communication,' which reveals the problem of communication between the two fields. Finally, there are perceptions about the social context and insufficient regulatory environment. C4 refers to the social context that affects the ESS market, such as the government's 'policy' support and 'PVs.' C5 means a regulatory environment that lacks 'Test' to 'Secure' the 'Safety' of ESS internal components. In summary, the network in the battery field recognized 1) the fire risk of batteries, 2) the division of specialized areas according to majors and communication problems, and 3) the insufficient regulatory environment through the sub-communities.

The following is the semantic network structure of **the electric control field**, which consists of a total of 7 communities.

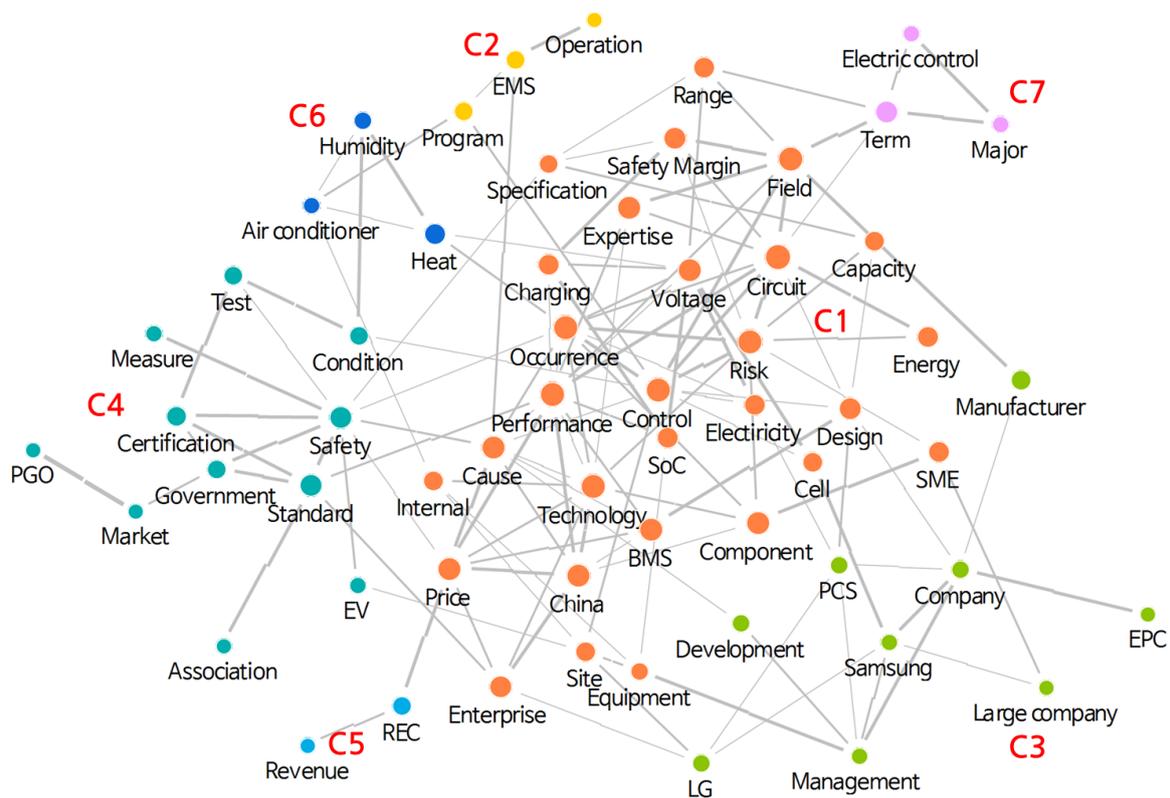


Figure 5.5 Semantic network of EC with Community analysis on ESS organization (Modularity 8.026, over 3.75)

C1 is connected with the main components of the ESS ('Cell' and 'Circuit') and the 'Cause' of the fire. The community includes the most nodes, and means that failure to control the fire risk can lead to a fire. As a measure to control 'Heat' in C6, 'Air conditioner' is connected. However, this perception may show the lack of understanding battery fire risk in the electrical control field. It is more important to manage the temperature inside the cell by controlling the electrical abuse of the battery, such as excessive charging and discharging, rather than managing the temperature with an air conditioner (Liao et al., 2019). In the end, although efforts are made to control the fire risk of the ESS, the risk may not be managed properly due to insufficient understanding of the battery fire risk.

In C7, like the battery field, the electric control field recognizes the difference in 'Term' according to the 'Major'. In particular, the difference in terms is one of the significant issues that can cause communication problems in the interaction of the two fields. C4 relates to 'Measures' related to 'Safety'. The community is composed of 'Standards' and 'Certifications' that constitute the insufficient regulatory environment. Moreover, it recognizes that 'Test' and 'Certification' are necessary to ensure safety. Therefore, the limitations of the private organization standards mentioned in ch.5.1 are also revealed in the network analysis. The connection structure of nodes called 'Association' connected with 'Standard' represents the power related issues with regulation.

Finally, the network structure of **fire victims** consists of a total of four communities, and they are aware of ESS and fire accidents, mainly focusing on the pursuit of economic benefits. The overall network structure is as follows.

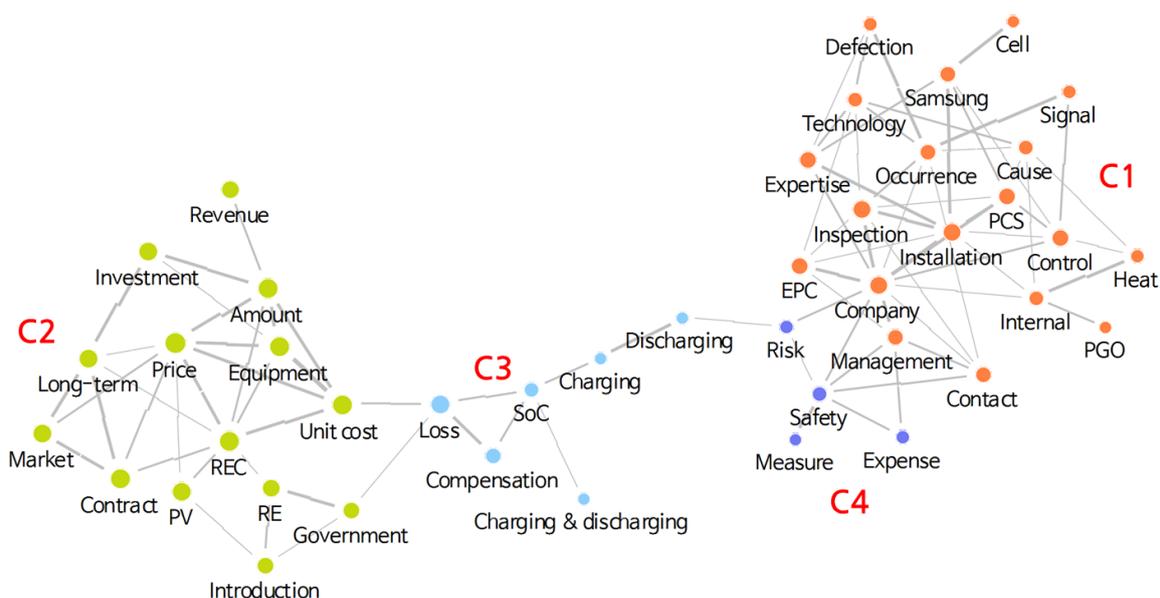


Figure 5.6. Semantic network of fire victims with Community analysis on ESS organization (Modularity 4.279, over 3.75)

C2 represents the social context for 'REC' and 'PVs' of 'Government'. In this social context, fire victims made investments to install ESS. In C3, node connections that recognize 'Charging & discharging' as economic 'Loss' appear centering on 'SoC' limitation. That is, in the other two fields, the nodes (SoC and Charging & discharging) are viewed as conditions for battery abuse or risk management, while fire victims perceive them as obstacles in pursuit of profit. C1 means that the fire victims are private power generation operators, and most of them install ESS through the construction of 'EPC' and 'Company' and receive continuous 'Management' and 'Inspection'. C4 shows that the government's safety measures (SoC restriction) are recognized as an obstacle to ESS operation. Government regulation is perceived as a 'Cost' that private power generation operators must bear.

It is noteworthy that there is little awareness of the cause of the fire in the network structure of the fire victims. In the end, it can be said that private power generation operators perceive ESS as a means of pursuing economic profits rather than technological artifacts. This perception can be interpreted as the fire victims perceived the ESS as a Black box and effective means to accomplish its purpose rather than considering the fire risk of ESS.

5.2.3. Summary

Through SNA, various perceptions of relevant social groups shown in the interview data were analyzed quantitatively. And it was possible to find a semantic map that revealed social context change, association, and distinction of social groups by Major field, communication (term) problem, the difference in fire risk perception, and ESS (Black box) technology for pursuing profit.

Summarizing the results of network analysis can be summarized as follows. There is a difference between the battery and the electric control field. The battery sector was very aware of the dangers of the battery itself. Various conditions under which thermal runaway occurs were recognized. On the other hand, the electric control field tried to control the risk rather than understand the risk of the battery itself and recognize that the failure of the control was the cause of the fire. There were difficulties in communication between the two different majors. In Fig 5.7, fire victims perceive the ESS as an economical means rather than a risk, and from the end user's point of view, the ESS can be perceived as an efficient means, without doubt, that is, a Black box. In the end, Chapter 5.2 is meaningful in that it exploratory found significant issues of ESS technology & fire causes due to the interaction of RSGs. The following figure summarizes the issues derived from the codes derived from TA and the connection structure of major nodes shown in SNA.

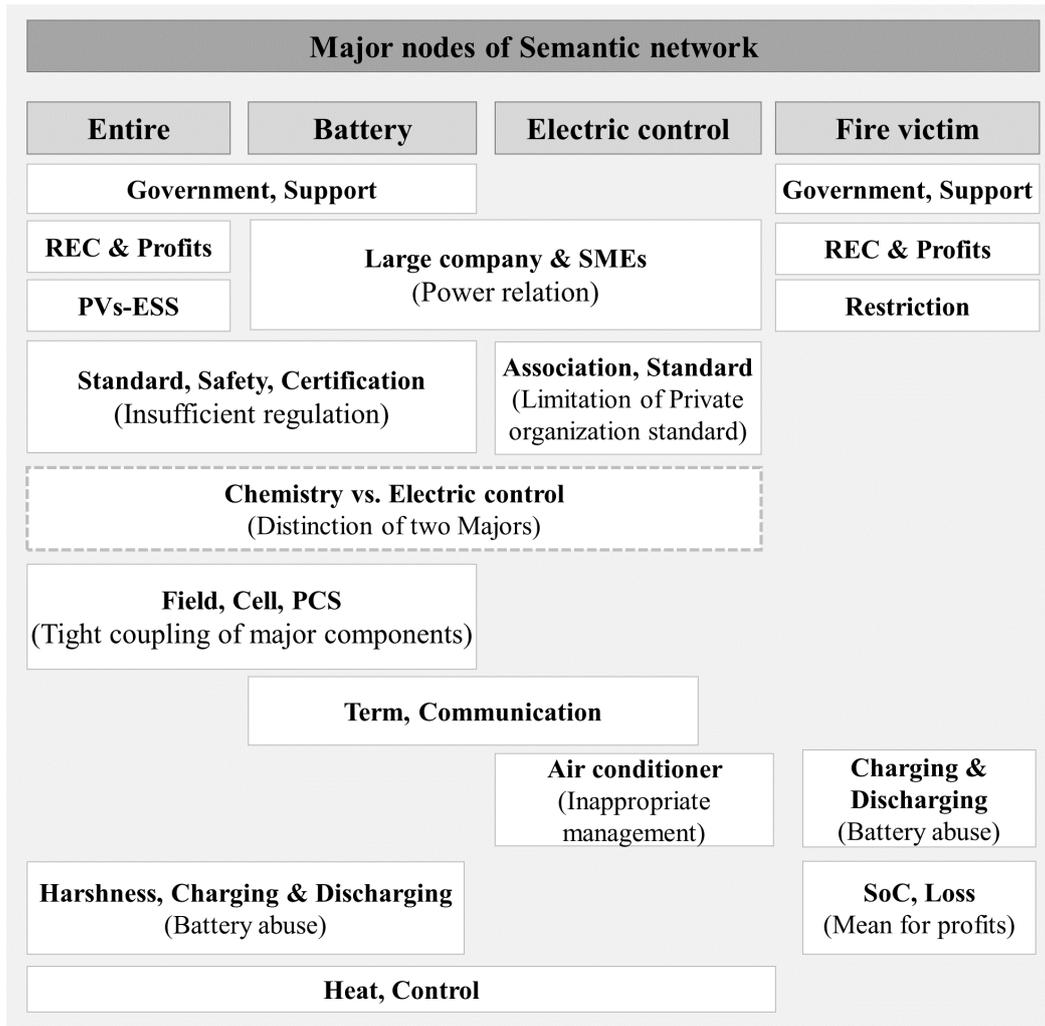


Figure 5.7 Semantic network analysis result by RSGs

Chapter 5.3 examines the inside of the Black box (ESS technology) in detail, focusing on issues found in network analysis through Thematic Analysis. For example, the interaction of batteries, electrical controls, and private power generation operators. Moreover, there is a relationship between this interaction and the fire occurrence. Because, when analyzing interview data in SNA, some nodes with important meanings may be removed by co-occurrence frequency or normalized weight value. As a result, some critical issues could not be considered due to the methodological limitations of SNA. Thematic Analysis takes an in-depth approach to qualitative interview data and uncovers significant issues that were not revealed in SNA.

5.3. Opening ESS fire accidents: Hidden fire causes in Black box

RSGs of ESS technology have started to use the finally adopted technological artifacts without a doubt. ESS was utilized by the social groups pursuing the interests of each group and began to spread rapidly in society. When a technological artifact is stable and works efficiently, it is perceived as Black box in which no one pays attention to the internal complexity of the technical artifact (Latour, 1999). Socio-technical disasters like ESS fires are not sudden events but accumulated over a long period and developed in stages (Aini and Fakhrol-Razi, 2010). However, continuous fires occurred in ESS, and it was necessary to open the 'Black box' to find the causes. In the process of socially constructing ESS technology, the interaction occurs by relevant social groups. The interaction refers to the conflict and negotiation process based on the interests of each social group. In conflict and negotiation, small deviations can be made and accumulated that can affect the occurrence of a fire. Therefore, ch.5.2 examines the interaction of RSGs that occur within Black box (ESS technology) and identifies the relationship with fire.

Qualitative analysis is conducted on the data collected through interviews with various members of relevant social groups. In particular, it analyzes the social structure of ESS and the risk perception and usage experience of ESS workers. Thematic analysis is conducted on issues related to ESS technology and fire risk. TA performs in-depth analysis based on significant issues derived through SNA, an exploratory analysis previously. In addition, other significant issues that are not derived due to methodological limitations of SNA are also reviewed. This chapter focuses on providing a logical basis and sufficient explanation for the research hypothesis that the fires were caused by the interactions of relevant social groups within Black box. Therefore, the interactions are analyzed using the main concepts of the accident approach models. ESS fire accidents and risks are investigated by considering Environment, such as policies and regulations, Structure and Process of the ESS organization, and Cognition/ choice of the organization's members.

5.3.1. Environment

The environment can influence the activities of relevant social groups and members to achieve their goals. The elements constituting the environment have social context and culture, and changes in environmental factors can affect the achievement of goals and activities of social groups.

Government support and regulation

The social context is acting as an environmental factor that can have various influences on the social construction of ESS technology. The elements constituting the environment have social context and culture, and changes in environmental factors can affect the achievement of goals and activities of social

groups. ESS has proliferated through policy support of the government in the era of energy transition. Manufacturers of major components of ESS predicted that the importance of ESS would increase as the social context changes.

*“The government's policy is to reduce nuclear power plants and use renewable energy as an alternative. But **RE has an intermittency problem**. In the case of PV, electricity is produced only during the day. By the way, users still use electricity at night. **But PV doesn't produce electricity at night**. So, the government can supply electricity stably by using **ESS**. That's why the government needs the ESS.”*

(C, PCS, 2020. 08.18)

Government support policies can be divided into two categories. One is the mandatory installation of ESS by public institutions and a special rate discount, and the other is to provide a REC weight of 5.0 to ESS linked to renewable energy. In particular, the provision of REC weight increased the demand for ESS in the private business sector. After all, this demand of the private sector has attracted many companies relevant to ESS technology.

*“As renewable energy power generation became influential and many companies became interested in ESS. Especially since the **government said it would give economic incentives (meaning REC 5.0) to ESS**, the number of companies that want to manufacture ESS suddenly increased. And when the fire broke out, all the companies called ESS disappeared. After all, there were so many companies in the market because of economic benefit from **REC 5.0 weight**.”*

(C, PCS, 2020. 08.18)

Suspensions have also been raised that REC weight 5.0 is provided only to ESS. Lee (2017a) pointed out that the Park Geun-hye administration intensively fosters the energy industry, and large companies that manufacture batteries receive preferential treatment from ESS support policy. In response to these suspicions, some ESS industry insiders mention that the administration was trying to create demand for lithium-ion batteries produced by large companies.

*“The battery applying the ESS and Electric Vehicle (EV) is (qualitatively) different. The batteries used in EVs are very high-class. However, low-quality batteries are made due to production yield. These **low-quality products can't be used in EVs, so they're supplied to ESS. Because there's gotta be some sort of low-grade battery somewhere in demand.**”*

(N, Battery, 2020. 11.13)

The above interview shows that the interests of the government (expanding the ESS market) and battery manufacturers (selling low-quality lithium-ion batteries) may have coincided. And this coincidence of interest may be one of the factors that led to the provision of REC 5.0 weights for ESS.

Changes in the social context due to policy support also affected ESS manufacturers. An increase in the demand for ESS leads to a profit for companies that manufacture ESS. So, companies even a little bit related to ESS technology tried to enter the market. However, there are cases in which small companies lacking technological expertise also enter the market and manufacture components of ESS.

*“**There are few companies in the market that specialize in ESS. Just like plant projects, several companies gather together to bring their own parts and assemble ESS. Such companies can only make some parts, but they say they can develop and install the entire ESS. There are a lot of companies in the market that exaggerate their technology.**”*

(D, BMS, 2020. 08.18)

Therefore, the lack of a regulatory environment can increase the likelihood that products with poor performance will be produced. There were many cases where many companies that a little bit were even related to ESS technology took ESS as a new business model. Support policies influenced that many companies flocked to the market, but there were also limitations in insufficient regulation. Before fire accidents, ESS regulations lacked details to secure safety functions because the commercialization period of ESS technology was short to detect potential technical defects in various operating conditions.

*“Companies that produce ESS products try to secure their safety through certification or testing. **However, even after these tests, some aspects are not sufficient.** Although there*

are private organization standards, simple KC certification, and European IEC standards, indeed, those standards are not sufficient to secure all the safety issues that are revealed in the industry field. Of course, KC is also a part of this, but KC certification alone is not enough for ESS fire risk.”

(H, Battery, 2020. 11.04)

The limitations of this regulatory environment can threaten the product safety of some small and medium-sized companies that lack technological expertise. This is because there are only safety regulations for the main components (battery and PCS) inside ESS, and there are no regulations on finished ESS product. According to the only private sector standard for finished ESS products (KS C 8548), it pointed out the necessity of securing the safety of the ESS in general, and there were few specific details such as how to prevent fire at any level and by what method.

Power relation

Power relation exists among the relevant social groups constituting ESS market. Power relation between battery manufacturers, manufacturers of electrical control components, private power generation operators, and governments can influence an adopted form of ESS technology. As mentioned earlier, battery manufacturers are dominated by a small number of large companies, while electrical control component manufacturers are made up of numerous small and medium-sized enterprises (SMEs) (Hong, 2017). Moreover, battery manufacturers and SMEs that produce electrical control products have the following power relation.

“Cooperation for EVs still hold hegemony in automakers not battery manufacturer. Conversely, in ESS manufacturing, battery companies have the dominance in cooperation. So, in the ESS market, PCS manufacturers cannot win the competition for dominance from battery manufacturers. “

(N, PCS, 2020. 11.13)

Many SMEs of electric control field are subordinated to a few large battery companies. This power relation is created because batteries are important component for energy storage and are supplied by a small number of large companies. Therefore, the power relationship among relevant social groups depends on the size of the company and the importance of internal component of ESS.

The strong power of battery manufacturers can also influence the government. An expert in the ESS industry points out that the power of the battery manufacturer may have influenced the government's official investigation. Especially, some suspicions were raised in that the results and details of the investigation were not clearly disclosed to the public.

*“If the battery manufacturers mention that the cause of the fire is their own problem, the export of their products may suffer. It's a complex mix of those things. That is why the government does not properly disclose the truth of the fire accident. While the official investigation report should disclose the cause of the fire, investigation process, and the results, **these details have not been properly disclosed at present. Investigating on fire accidents and no provision of full investigation to the public is not because it's really secret, but because it's difficult to open for public.**”*

(D, BMS, 2020. 08.18)

Eventually, suspicions were raised that the results of the investigation were made public by powerful social groups such as battery manufacturers. In fact, the details of the results of the first investigation were made public at the time. Through this process, questions about the causes of fire accidents have increased, and the fear of fires had grown due to the continuous occurrence of additional accidents.

As for the limitations of regulations, details on securing detailed safety are also important, but it is necessary to examine the background of insufficient regulations. Power relation shapes regulation. Before fire accidents, only private standards existed instead of national compulsory standards, and the standards of private organizations had the following limitations.

*“When creating private organization standards, the people who make it need to understand the whole real ESS technology. However, most standard-making procedures **are not like that at all. For example, some companies gather to form an association. So, when the new private organization standards are established, it's about companies that are members of the organization.**”*

(C, PCS, 2020. 08.18)

Since the private sector standards for ESS technology are composed by private organizations related to the technology, there's a consideration between tight safety regulations and the pursuit of corporate profits. After all, private organizations have the potential to create safety standards that include only the minimum safety regulations while preserving the interests of their members.

In particular, the insufficient regulatory environment made it possible for ESS-related companies to obtain legitimacy and pursue profits if they had minimum safety devices within the regulation boundary.

*“Other places (ESS manufacturers) did not take additional safety measures. That way, more money will be spent. **So there was a widespread atmosphere of not taking safety measures that were not legally necessary cause of costs. This is the most critical part of the fire.**”*

(C, PCS, 2020. 08.18)

In particular, the insufficient regulatory environment made it possible for ESS-related companies to obtain legitimacy and pursue profits if they had minimum safety devices within the regulation boundary. In the end, such insufficient regulations made the companies that design and develop ESS products pursue the maximum profit with the minimum safety measures.

Culture (Chemistry vs. electric control)

The ESS configuration is mainly designed by battery and electric control manufacturers. These two manufacturers can be distinguished by their majors. Battery manufacturers and electrical control manufacturers cooperate to assemble ESS, but certain differences occur between the two social groups due to differences in Majors. Cultural elements were found in the interview materials. In particular, the two fields show the difference in knowledge, understanding of technology, and even differences in the propensity of members for each Major fields. Due to these differences, the two Majors form cultural factors such as indifference to each other beyond the knowledge level of technical understanding, and what distinguishes them from each other is revealed in the interview materials.

The following shows the differences in the propensity of members according to the differences in their Majors. Moreover, for this difference in propensity, members of each Major filed recognize that the culture is different from each other.

*“The culture of electrical control and mechanical devices is straightforward. They're very direct when they talk. When I have a conversation with them, **they're almost like construction workers. It's not as timid as our battery field. We (Technology-interest alliance) have very different cultures.**”*

(W, Battery, 2021. 01.27)

These cultural differences are also reflected in the perception of technology. The difference in perception of technology is revealed by indifference to each other's majors. For example, there is a difference in perception of the battery, which is an important component of ESS.

*"In my opinion, battery and electrical control fields don't really care about each other. Those who control electricity think, '**This is not my problem**' about the battery problem. Even battery manufacturers are not interested in those who make electrical control manufacturers (BMS, PCS). **Each person only cares about their own field.**”*

(N, Battery ,2020. 11.13)

Furthermore, workers in the two majors say that they are culturally different from each other. They mention that different cultures by Major are influencing the understanding of certain technologies of ESS.

*"Chemistry and electricity control have different cultures. The two majors are different from way of thinking about problems. Chemistry is very statistical. Electrical control (circuit side) requires the input and output to fit perfectly. For example, people in chemistry understand that there can be a probabilistic risk of batteries. **But electric control doesn't understand the battery field's way of thinking.** If it is designed to work perfectly, why do errors occur?"*

(K, PCS, 2020.11.05)

In the end, chemistry and electric control Majors understand ESS technology based on the dominant values and beliefs of each group. In the field of electric control, they do not understand the probabilistic recognition of technological problems by culture of chemistry filed.

The social contexts and cultures that make up the environment can influence the activities of relevant social groups. Changes in the social context, insufficient regulation created in power relation, and the legitimacy of the social group's profit-seeking activities acquired within the boundary of the regulation had an impact on relevant social groups. Moreover, the difference in majors of relevant social groups was not just a difference in knowledge but was acting as a cultural environment.

5.3.2. ESS organization (Structure & Process)

ESS organization is a Technology-interest alliance of RSGs. The social groups that are members of the ESS organization are an alliance that pursues the interests of each group through ESS technology. This alliance shows some organizational characteristics that several relevant social groups interact with and distinguish each other based on ESS technology and their interests.

1) Structure

Structure refers to the connection of relevant social groups. Structure influences the accomplishment of each group's goals. Two characteristics are revealed in the structure. One is the tight coupling of batteries and electric control components of ESS. The other is the flow of information between the two manufacturers, that is, the problem of communication.

Cooperation of RSGs (battery and electric control manufacturers)

The overall configuration of the ESS is a combination of a battery that can store energy and an electric and electronic circuit that controls charging and discharging of the battery. ESS has various operating conditions such as charging and discharging within a predetermined voltage range and controlling the State of Charge (SoC) regarding battery for stable electricity storage and supply. The process of charging and discharging rapidly reacts with the ESS operating conditions. Therefore, in ESS configuration, battery manufacturers and electrical control circuit manufacturers have a tight coupling form of collaboration.

"There should be experts in the field of electrical control (in the development of ESS).

*Battery manufacturers like us also need electrical control parts to make ESS. **So our***

company has a variety of majors, including chemistry, electrical control, mechanical engineering, and telecommunications."

(H, Battery, 2020. 11.04)

As such, battery and electric control manufacturers and others are cooperating to produce ESS. One expert points out the technical complexity of the ESS itself. In particular, he points out that products in various fields are tightly coupled, and incorrect charge/discharge control can lead to thermal runaway of cell in ESS.

*"I think that the **technical complexity of ESS is quite high**. Few companies can produce ESS exclusively in one company. **ESS production is linked to various companies**. For example, **Samsung and LG are companies that manufacture battery cells**. The electric control product (PCS) manufacturer brings the battery cell and assembles it. lithium-ion batteries can explode if you abuse battery such as overcharge. Not only one explodes, but the cell next to it explodes as well."*

(J, Battery, 2020. 11.05)

As the various technologies are coupled, the technology's risks are also increased due to the technical complexity. And these risks can be challenging to control in the combined structure of the various relevant social groups.

Communication issue

A number of ESSs connected to PVs are made by SMEs that mainly produce PCS. For example, SMEs that manufacture PCS procure batteries from outside because they cannot manufacture every component of ESS. Therefore, electric control manufacturers cooperate with battery manufacturers to assemble ESS. And this form of cooperation can lead to communication problems.

*"Like our company, all the designs and production are done in one place, and each department can communicate. For example, when a company develops an ESS, **it's very***

difficult to communicate with each part if they buy PCS, buy batteries elsewhere, and outsourced PMS or BMS programs to develop and assemble them for finished ESS product."

(C, PCS, 2020.08.18)

The structure of cooperation as product procurement creates difficulties in communication. Simply procuring major parts is not a transfer of expertise, so it is difficult to understand the other specialized fields. For example, it is difficult to understand how each other's technology and knowledge interact in the process of utilizing (design, development, and installation) an ESS.

Electrical control manufacturers perceive the battery as one of many parts of the entire system, and the perception of the fire hazard of the battery itself is different from that of battery manufacturers. And regarding the difference in risk perception of technology, major relevant social groups point out that there is a structural wall in the other's expertise field.

"There's a wall between the battery and electric control. All the information is not open to each other. Regarding battery technology, operating conditions, and risks, new electrical control companies in the ESS market were unable to grasp information about batteries. This is caused by some kind of vague structural problem."

(K, PCS, 2020.11.05)

There was an invisible structural division between the two major relevant social groups. This caused problems in communication, such as information transfer between the two groups.

A communication problem, that is, a cooperation structure with poor information transfer, may have a damage on the battery, a major component of ESS. In the field of electric control, which lacks an understanding of battery characteristics, it may be difficult to comprehensively consider the causal relationship between various operating conditions of ESS and fire.

*"Many of the electrical experts couldn't understand the voltage curve of the battery properly. There is a difference in voltage curves for each battery. And it can be a problem if you mix and use batteries. Suppose the battery is mixed and ESS is configured. **In that***

case, it can work in the beginning, but damage can accumulate inside the battery. But unless you're a battery professional, it's hard to recognize abnormal signals from internal battery damage."

(G, Battery, 2020.08.18)

Finally, communication difficulties and inefficiencies in information transfer in cooperation structures can affect fire risk. For example, a battery manufacturer provides specifications for a battery and offers general operating conditions for an appropriate operating temperature and voltage. In addition, the detailed operating conditions of the battery and the electrical characteristics of the product were not completely disclosed in terms of technical security. The transfer of such incomplete specialized information makes it more difficult to understand the risks in various ESS usage conditions. After all, it is difficult for ESSs to properly manage the thermal runaway risk of batteries considering only the general specifications given by battery manufacturers.

Battery and electrical control manufacturers can create 'structural secrecy' when proper information is not transferred. Insufficient transfer of expert information can contribute to the risk that the ESS can lead to thermal runaway and fire.

"Battery manufacturers provide battery specifications to electrical control manufacturers. The specification sheet is a voltage curve for only one condition. By the way, these voltage curves don't come out as well as shown in the specification sheet. Usually, the battery's performance is worse than the specification sheet. However, battery manufacturers don't offer all of that. If the battery manufacturer reveals all the characteristics of their products, it will fully reveal the level of technical skills on battery manufacturer. There's no battery manufacturer that opens up information like that."

(K, PCS, 2020.11.05)

Electrical control manufacturers that make ESS using batteries need specialized information on batteries. And it is possible to secure the safety of the ESS through the electrical control reflecting this information. However, difficulties in communication and 'structural secrecy' act as structural limitations in this cooperation. After all, structural limitations make it difficult to control the fire risk inherent in ESS.

2) Process

Process means that the interaction of relevant social groups systematically produces intentional or unintended outcomes. The factors that the interaction of various relevant social groups within ESS organization can influence fire accidents are 'accomplishment pressure' and 'deviance amplification'. First, accomplishment pressure is a factor that puts pressure on social groups on activities to achieve their goals, such as 'conflicting goals', 'pressure on performance', and 'deadlines'. Second, deviance amplification affects adverse outcomes by accumulating negative activities that occur through interactions within organizations. These deviances can accumulate over a long period and lead to accidents. The influence of the interaction of social groups on fire accidents through these two conceptual elements is analyzed.

Deadlines of support policies and social groups' response

The government's support policy had a significant impact on the social construction of ESS technology. And with these environmental changes, the relevant social groups within the ESS organization had various interactions. Economic incentives had a significant influence on determining the supply and demand of ESS. As mentioned earlier, the REC weight given to the ESS was designed to be gradually reduced, which acted as a kind of pressure to push the achievement of each group's goal.

"The REC weights provided by the government are getting smaller. This is directly related to profitability. And for ESS manufacturers, double-triple safeguards are needed to enhance safety, and the installation cost of the system must be raised. People who are considering a private power generation don't feel worth investing to ESS because of the low profitability."

(U, PCS, 2020.11.26)

For RSGs seeking economic benefits through ESS, the planned reduction of REC weights can seriously impact benefit pursuit. A reduction in economic incentives can be a kind of deadline. The supply also increased along with the demand for ESS by private power generation operators. However, to pursue the maximum profit during a limited political support period, ESS had to be developed as

soon as possible. In the end, the deadline led to the failure of major social groups to establish a proper cooperation process and secure the technical perfection of ESS.

"To strategically develop PVs, the government actively supported ESS, and it quickly spread and installed. Still, the government, battery manufacturers and electrical control manufacturers should have established a process for cooperation among the companies. I think they didn't have much time for the process cause the ESS spread went too fast."

(F, Battery, 2020.11.02)

Specific pressure exists in designing and developing ESS due to the rapid increase in demand for ESS. In order to keep up with ESS demand and supply, ESS manufacturers had to rush to produce finished products.

"If you do a demonstration test (for safe and normal use of ESS), it takes a lot of time. And you have to show the results that work well through empirical tests. As a result, if the ESS development schedule is intertwined, it may not be possible to perform rigorous empirical tests. Through this process, the product may become incomplete."

(H, Battery, 2020. 11.04)

In the end, the interaction of major relevant social groups caused by the deadline lowered the technical maturity of the ESS and resulted in inherent risks.

Fire risk amplification with accumulated small deviances

Adding safety devices to ESS can be economically burdensome. Some manufacturers with limited resources, such as SMEs, have difficulty in adding safety functions beyond legal regulations. In the end, some ESS manufacturers are struggling between pursuing profits and adding safety features. Insufficient safety measures create and accumulate small deviances that occur in the process of ESS design and development.

“(Monitoring) cannot detect overvoltage appearing in the battery cells if the monitoring interval is long. Companies just have to pay to add detecting features, but no companies actually add features like that. Therefore, even if overvoltage occurs in the battery, the monitoring interval is long, increasing the possibility that the electrical control system cannot properly monitor the abnormal signal. However, continuing to do so (overvoltage on battery) will damage battery cell.”

(D, BMS, 2020. 08.18)

Although it recognizes the fire risk inherent in the ESS, insufficient monitoring technology that cannot detect abnormal signals was used. And this flawed risk control technology can increase the fire risk of the ESS. Such small deviations went through the process of gradually accumulating inside the Black box called ESS. Eventually, the increased risk of accumulated deviations may have affected the thermal runaway of batteries in ESS.

Small mistakes and deviations from interactions between major social groups accumulate, revealing a causal relationship leading to fire accidents. It can be explained that the fire risk is not simply due to technical flaws but that many small deviations that affect these technical flaws affect the occurrence of fires over a long period.

5.3.3. Cognition/ choice

Cognition and choice refer to the behavioral factors of members of relevant social groups constituting the ESS organization. Cognition and choice are influenced by the dominant values and shared beliefs of social groups and affect the behaviors for goal achievement. The behaviors of social group members involved in the social construction of skills can lead to best, sub-optimal and adverse outcomes. There are effects of socially constructed ESS technology as Black box on Cognition/ choice. ESS technology used without any doubt about the dangers of the technology can lead to fire accidents. The following interviews describe that electric control field perceives battery as no doubt on the technology.

“ As I said before, those who belong to electric control field trust the battery experts and just used battery. At the ESS installation site, batteries were almost treated as brick-like building materials.”

(X, Battery, 2021. 01.27)

“Many people do not know about the characteristics and risks of batteries. And the people who manufacture PCS or something like that just took the battery and utilized for other products, but they don't really know the technical characteristics of the battery.

(D, BMS, 2020. 08.18)

As such, the electric control field states that there will be few problems rather than sufficient understanding of the fire risk of battery. In Electrical control field, these blind trusts in battery technology as Black box are revealed several times.

Members of RSGs take various actions to achieve the group's goals to which they belong. These behavioral factors can influence the occurrence of accidents. First is 'disqualification heuristic'. Members may underestimate the risk of technology or perceive the risk as acceptable. Second is Normalization of deviance. Normalization of deviance means that members of the groups recognizing risk signals as normal even if the risk signal is genuine. The dominant values and beliefs of each group make members accept abnormal factors (behavior, perception, Etc.) as normal. Due to this, even if some members of the group recognize risk signal, the group recognizes the risk signal as normal, so this cognition may make an irrational choice to ignore the danger signal. Finally, human error refers to the mistakes of group members, mainly due to a lack of understanding and experience in technology.

Disqualification of Battery fire risk and harsh ESS operation

Private power generation operators using ESS were not aware of the fire risk. Most private power generation operators entered the ESS market by considering only the REC weight and profitability.

“The company (who installed ESS) didn't explain the risk of fire at all. We never imagined there would be a fire at ESS. And power generation operators often install ESS without knowing the ESS technology properly. The electric control company managed and inspected the ESS, so the private power generation operator had nothing to do with it.”

(Q, fire victim, 2020.11.19)

Eventually, a continuous fire accident occurred in the ESS. One of the major factors influencing the accident is the disqualification of the fire hazard of the battery. Large companies with trust in technology manufactured the batteries used in ESS, and since battery technology was recognized in other fields such as EVs. It was able to acquire the blind trust from relevant social groups (Park, 2015). So, when the battery manufacturer supplied the members of the electric control manufacturer with the battery for ESS from the battery manufacturer, they did not have much doubt about battery performance and safety.

“(Before the fire), everyone thought, ‘It’s a battery made by Samsung and LG, will there be any problems?’ So everyone thought that batteries manufactured by large companies were the best in the world. It’s just that everyone trusted the technology of large corporations without knowing it properly.”

(N, Battery, 2020. 11.13)

The battery with the technology of a large manufacturer has made ESS designers devalue the fire risk of the battery itself. In particular, the batteries used in the early days of ESS design were utilized the most advanced batteries for EV (Electric Vehicle).

“The certification for that (battery) is a product that has undergone extremely harsh testing, and it is a product of a large company. So, it is very rare that this (battery) itself becomes a problem.”

(C, PCS, 2020. 08.18)

The battery for EV was the most advanced technology at that time, and it was a product that endured safety tests. However, unlike the charging/discharging cycle of EVs, the failure to properly consider the harsh operating conditions of the ESS, which repeats charging and discharging every day, had an impact on the occurrence of battery thermal runaway.

“The batteries used in ESS have been verified by EVs for a considerable period of time. Everyone thought that there would be no problem in using this proven battery in the ESS without having to carry out a tight empirical test. EV batteries are guaranteed for 20

years. Of course, the battery companies thought so too. But come to think of it, ESS is charged and discharged every day. Compared to the battery operating conditions of EVs, these conditions were ridiculously harsh.”

(X, Battery, 2021. 01.27)

In the end, the ESS design and development side did not properly consider the risks of battery technology according to the conditions of use of the ESS. And rather than understanding battery technology, electric control manufacturers considered only the specifications provided by the battery manufacturers. Even battery manufacturers were unaware that ESSs can operate harshly and subject to electrical abuse.

Furthermore, private power generation operators also began to utilize ESS harshly, without any doubt. In order to get high profits through ESS, they have to repeat the process of charging and discharging the generated electricity to the battery as much as possible. In the end, ESS operation situation before the fire led to battery abuse.

"The conditions under which ESS is profitable are fully charged and completely discharged every day. Some companies even did that ESS charge and discharge twice a day. If you compare the harsh conditions of use of these batteries, The battery usage method in existing electric vehicles does not repeat charging and discharging every day. However, ESS Charging and discharging every day is that harsh on the battery. For example, the battery usage method of EV uses 10,000 Km per year, whereas ESS uses 100,000 Km per year."

(X, Battery, 2021. 01.27)

In the background of such battery abuse, private power generation companies perceived ESS as an economical means only. In the end, the perception of social groups that lacked understanding of technology and prioritized profitability impacted ESS fires. Especially, ESS technology is perceived by relevant social groups as a 'Black box' that allows them to pursue their interests without adequately considering the risks inherent in the technology itself.

"The company that installed the ESS told us at first that we could use 97 percent of the battery charge. And you have to produce as much electricity as possible through ESS to make a lot of profits. So we used ESS charging 96-97% or 95% of the time (from the installation company) as recommended."

(T, fire victim, 2020. 11.25)

Neither battery nor electrical control manufacturers considered the actual operating conditions of the ESS. Eventually, damage from electrical abuse accumulated in the battery cells inside the ESS. However, none of the relevant social groups were able to assess these risks until fire accidents broke out properly. In other words, relevant social groups recognized and utilized ESS as a 'Black box' due to risk disqualification and lack of expertise.

Normalization of fire risk

Previously, members of relevant social groups underestimated risk. Cognition of these risks can be extended to discussions of 'acceptable risks' and 'irrational choices'. For example, there is a big difference between knowing about the fire risk of battery and understanding the mechanism of battery thermal runaway in ESS. This difference in perception of risks can create acceptable risks and be embedded in the ESS design and development process.

"Companies that develop ESS think too easily about the dangers of batteries. It's rare for a battery to have a thermal runaway for no apparent reason. However, since it is man-made, problems may arise. Considering all of these problems, the ESS has to be designed. But even if ESS manufacture don't consider it technically to that extent, the ESS is produced and operated quite well."

(C, PCS, 2021. 01.27)

For those who designed the entire ESS, the battery was just one of the internal components. Therefore, rather than comprehensive consideration of fire risks, the focus was on the ESS to function correctly first, such as charging and discharging. In the end, rather than focusing on the signals of danger

that exist inside the ESS, they focused on selling and utilizing ESSs that just working on basic functions without sufficient safety measures.

“ESS manufacturers think of batteries as components, so if they design a system with basic functionality, problems arise. For example, if the technology of electric control products is insufficient, an error occurs in the middle of the ESS operation. Fire accidents happen a little more regardless of the size of the company, and problems arise when people with less expertise in batteries design ESS.”

(H, Battery, 2020.11.04)

Acceptable risks cause members to make irrational behavioral choices. If the battery is overcharged and over discharged, the risk of thermal runaway increases (Bubbico et al., 2018). Through ESS, they made choices according to their interests. ESS manufacturers and private power generation operators accepted the risk based on their blind faith in the batteries produced by large companies and made risky choices such as overcharging and over discharging to pursue maximum profits.

“Most of the companies that receive batteries and manufacture ESSs would have thought that even if the SoC was used up to 95%, there would be no fire. Otherwise, most ESSs would not have thought of using SoC up to 95% before the fire. And both LG and Samsung batteries are large manufacturers. So, there could have been some kind of confidence or had some blind trust that the battery wouldn't pose a fire risk

(U, PCS, 2021. 01.27)

Moreover, private power generation operators have chosen to use up to 95% of the SoC for daily charge and discharge to increase profitability. Irrational risk choice can lead to fire accidents.

Interviews with fire victims focus only on business feasibility and reveal their lack of expertise in technology. Fire victims, who are private power generation operators, often install ESS in consideration of business profitability. Eventually, the lack of awareness of the fire risk and battery abuse to pursue benefits can explain the process by which risky behaviors are normalized in the interaction of relevant social groups with ESS utilization.

Lack of expertise and ESS errors

Finally, there is also the problem of human error. The ESS technology had a short commercialization period, and there was a shortage of professional workforces. Industry experts point out the lack of expertise of those who install ESS in the field.

"Companies in the market today lack a lot of ESS installation and operational experience.

ESS hasn't even started yet. We're still in the monitoring stage. It hasn't been long since technology started to spread properly. We'll have to use ESS for another 10 years, and we'll be able to use it reliably."

(N, Battery, 2020. 11.13)

Such a lack of expertise can cause problems in the ESS installation process. Workforces with insufficient expertise may make human errors such as system fault mistakes when installing ESS, and some of them make intentional violations, such as hiding the mistakes. Ultimately, these human errors can lead to ESS fire accidents. In actual ESS fire cases of 28, there have been cases where a fire occurred during system installation or system repair (MOTIE, 2019; MOTIE, 2020).

"In order to install ESS, we have to directly connect all cables and circuits one by one.

There were cases like this. A system integrator company with insufficient expertise made a mistake while assembling the ESS. However, they keep assembling the ESS without knowing what kind of impact that mistake will have. And after assembly, the ESS doesn't work. Then we have to check every system joint to find these mistakes."

(U, PCS, 2020.11.26)

Summarizing the above, various negative interactions caused by cognition and choice may have influenced ESS fires. Risk perceptions of social groups were underestimated and led to the normalization of deviance from accepting the risk signal as normal by acceptable risk. Furthermore, human error of lacking expertise is acting as a cause of fire accidents.

5.3.4. Theme development and summary

There are several main relevant social groups, from the government that tried to expand the supply of RE through ESS, battery and electric control manufacturers that profit from ESS manufacturing and sales, and finally, businesses of private power generation operators. They recognized ESS technology as a 'Black box' and utilized it to pursue the interests of each group. However, as fire accidents occurred continuously, the Black box was opened and the effects of interactions within the ESS technology-interest alliance were analyzed on the fire occurrence based on the various concepts of accident access models.

The ESS fire accident was not simply a sudden event caused by a technical defect. ESS technology was socially constructed by interactions of major social groups in conflict and negotiations. Through environment, structure and process, cognition/choice, various causes that affected the fire accident were created.

A theme development process is carried out to derive a single theme that encompasses various issues discovered in the interview analysis (Vaismoradi et al., 2016). First, the issues revealed in the interview are organized into key data. Second, codes that can encompass them are derived based on key data and details. Codes are mutually exclusive between each code, encompassing key data. Finally, a theme that can encompass the extracted codes is developed. The developed theme is the essence created based on the experiences of all the participants collected through the interview and penetrates the entire interview content.

The key data confirmed through the interview are as follows. Various interactions exist among relevant social groups, and this has influenced the causes of ESS fires. The main issues that have affected the fire are change in a social context, power relation, cultural environment, the structure of relevant social groups, communication problems, deadlines, accumulation of deviances, disqualification of fire risk, normalization of risk, and lack of expertise. Based on this, key data was classified and derived through codes.

The fire accident was a structural problem affected by the interactions of the major relevant social groups that socially constructing ESS technology. Changes in the social context, the influence of the cultural environment, the structural limitations of the alliance organization, adverse effects of interaction, fire risk cognition, and the lack of expertise on fire risk affected the ESS fire accidents. Based on these key data, five codes were extracted through an analysis process. The first code is the social context. In relation to ESS, as the government's support policy (REC weight 5.0) was newly established and the demand and supply of ESS rapidly increased, relevant social groups and market growth occurred. Second, the cultural environment refers to differences according to the field of Major. Chemistry and Electric control fields have cultural factors such as people's propensity and indifference to each other's Major fields. Third, there is a structural limitation of the technology interest alliance.

Relevant social groups are interconnected to form a technology interest alliance. It has some structural characteristics of the organization. Fourth is the interaction among the social groups within the alliance. Interactions can produce adverse outcomes that can cause fires. Finally, there was a lack of risk cognition and expertise on ESS technology. The details of each code are as follows.

Table 5.9 Description of extracted codes

Key data	description	Extracted codes
Government support and the insufficient regulation	<ul style="list-style-type: none"> - Government's REC support policy and ESS market growth (increase in product demand and supply) - An insufficient regulatory environment lowers barriers to business entry (legitimacy and economic benefits pursuing) 	Social context
Impact of power relation	<ul style="list-style-type: none"> - Limitations of private organization standards - Leading power of battery manufacturers (Electric control manufacturers are almost SMEs) - Suspicion of government preferential treatment for large battery manufacturers 	
Cultural differences by field of Major	<ul style="list-style-type: none"> - The two majors (chemistry vs. electric control) are indifferent to each other. - Differences in the propensity of social group 	Cultural environment
Alliance of social groups	<ul style="list-style-type: none"> - Cooperation and tight coupling of battery and electric control products 	Structural limitations of the ESS technology-interest alliance
Limitations of communication due to structure	<ul style="list-style-type: none"> - Cooperation structure for ESS production - Incomplete information transfer due to different technical fields and terminology differences 	
The impact of social pressure on goal achievement	<ul style="list-style-type: none"> - Support policy with REC weights as 'deadlines' - Insufficient cooperation process due to rapid ESS market growth 	Adverse consequences of interactions
Accumulation of deviance and amplification of risk	<ul style="list-style-type: none"> - Adding functions to ensure safety is an obstacle to pursuing profits - Unable to detect risk due to insufficient safety technology 	
Disqualification of battery fire risk	<ul style="list-style-type: none"> - Blind trusts in batteries made by large companies - Underestimating Battery Fire risk - Harsh ESS operation and battery abuse (overcharge, over discharge) 	Lack of risk cognition and expertise on ESS
Irrational risk choice with 'Black box'	<ul style="list-style-type: none"> - Irrational choice (benefits vs. safety) - Private power generation operators perceive ESS as an investment tool for profit rather than risk itself. - Unquestioned use of technology and inherent risks 	
Lack of expertise and system error	<ul style="list-style-type: none"> - Short commercialization period of ESS - Lack of expertise (human error) and fire risk 	

What is unique is that the cultural environment is found in the difference of two Majors (Chemistry and Electric control). Battery manufacturers and electrical control manufacturers, which are relevant social groups of ESS, are classified according to their main products. There are still some differences in people's propensity in each field, approaches to technology, and indifference to each other depending on their Major fields. Moreover, under the influence of these factors, a cultural environment was created. Especially, culture is the dominant value and belief of related social groups and affects the groups' overall interaction, such as conflict and negotiation.

A theme was developed based on these extracted codes. The extracted codes show how the direct and indirect fire causes that generated in ESS were affected. ESS technology was Black box used by RSGs without any doubt, and the interaction (conflict and negotiation) of RSGs created various fire causes inside the Black box that no one looked at. The subject development process is shown in the table below.

Table 5.10 Details of theme development

Theme	Codes	Key data
Hidden fire causes in 'Black box (ESS technology)'	Social context	Government support and the insufficient regulation
		Impact of power relation
	Cultural environment	Influence of Cultural Differences by Major Fields
	Structural limitations of the ESS technology-interest alliance	Technology-interest alliance of social groups and ESS Complexity
		Limitations of communication due to structure
	Adverse consequences of interactions	The impact of deadlines on incomplete cooperation processes
		Accumulation of deviance and amplification of risk
	Lack of risk cognition and expertise on ESS	Disqualification of battery fire risk
		Irrational risk choice and technology without doubt
		Lack of expertise and system errors

Based on the exploratory analysis results of SNA, TA was performed for in-depth analysis. The TA developed the important issues revealed in the interview into a topic. The main cause of the fire was the

interaction of RSGs hidden inside the Black box. Interaction of RSGs caused adverse outcomes, which had negative effects that could lead to fire accidents.

6. Conclusion

The purpose of this dissertation is to confirm that the ESS is socially constructed and to explore the main factors that have influenced the occurrence of continuous fires in the interaction of relevant social groups. The process and results of interactions between major social groups related to ESS and identified the process in which ESS is socially constructed. It examines how the interests and conflicts of social groups arose and the impact these interactions had on the fires. Lastly, it identifies the cause of the fire and offers suggestions on ESS acceptance and future development direction.

6.1 Summary

Limitations of fire accident investigations

Continuous fire accidents have occurred in several ESSs installed in Korea. Fire accidents have led to a total reexamination of ESS technology, which was expected to contribute significantly to energy transition technology. Additionally, the government formed a fire accident investigation committee to determine the cause of the accidents (MOTIE, 2019). The first fire accident investigation suggested that the technical defects of the ESS and the problems that occurred in the overall system operation were the cause of the fire. Unlike the previous investigation results, the second investigation suggested that the battery was the direct cause of the fire (MOTIE, 2020). Although the government announced the results of the fire accident investigations, some stakeholders related to the ESSs presented opposing opinions, and a controversy arose. It is difficult for everyone to be satisfied with the official fire investigation results. However, experts indicate that the current fire investigation committee's investigation results lack sufficient explanation (Kim, 2020b).

As the two investigations of fire causes are different on the battery risks, the reliability issue of the official investigation results could act as a limitation of the committee. Moreover, there are other limitations as well. As mentioned in Chapter 4, fire accident investigations have limitations regarding the independence of the accident investigation committee and the bias of investigation contents. As the committee was organized under the government's leadership, it was not easy to review critical social contexts, such as government policies related to ESSs. Additionally, the composition of the investigation committee, centered on technical experts, led to an investigation focused on technical flaws. Biased committee composition might have had difficulty providing sufficient explanation for the impact of other aspects such as people, organizations, and society that could cause fires.

The social construction of ESS

Technology does not develop only on an efficient trajectory but is socially constructed through various interactions of relevant social groups of technology (Bijker et al., 1987). Each social group has

a flexible interpretation based on interests, and each interpretation of technology leads to conflict among relevant social groups. The final form of technology is adopted through a negotiation process that narrows the conflict between each group. Various interactions between groups occur during the negotiation process and influence the decision of final technological artifacts.

ESSs is a socially constructed technological artifact. Several social groups use ESS to achieve their goals, including the government, battery manufacturers, electric control product manufacturers, and private power generation operators. As suggested in Chapter 5.1, the following groups exist in the ESS: Battery and electric control manufacturers produce the major internal components of the ESS. Private power generation companies sell electricity using the ESS. The government promoted the spread of RE through the ESS support policy. These social groups united and interacted for their own profits. They negotiated with conflicts through strategic actions, and the final ESS artifact was adopted before the fire.

Fire accident and ESS as Black box

Socially constructed technology is recognized and accepted by relevant social groups in society. When these technological artifacts operate efficiently and reliably, society and major groups perceive them as a kind of Black box, used without paying attention to the internal complexity of the artifacts (Latour, 1999).

Similarly, ESSs experienced the social construction of technology, recognized as a Black box. As mentioned in Chapters 5, several RSGs utilizing ESS have created technological artifacts, leading to a rapid increase in ESS installations and market expansion. Relevant social groups merely pay attention to the technical fire risk of ESSs but use it to pursue the goals of each group. Regarding private power generation operators, the ESSs were used harshly to obtain maximum economic benefits. Eventually, the ESS has become a Black box, accepted and used without doubt for the alliance of social groups. However, since the fire broke out, it was necessary to reexamine these Black boxes.

Technology can be reexamined even after it has been socially accepted. Beck (2008) showed a case in which the Black box of nuclear technology was reexamined following a disaster caused by technological failure. Similarly, the insides of the ESS, Black box, also needs to be reexamined. Eventually, a Black box called the ESS was reopened. The social construction of technology makes it difficult to provide sufficient explanation for the interactions surrounding technology. Thus, there is a limit to reviewing the inside of the Black box. Therefore, several accident-approach models that consider the influence of social contexts on accidents were reviewed, and key concepts were utilized with operational definitions. Particularly, the conflicts and negotiations of social groups were explored, and the effects on fire occurrence were investigated.

Interactions inside the Black box and causes of fire

Through a literature data analysis, the process of the social construction of ESSs was reviewed. However, the data limitations affected the determination of interactions (conflict and negotiation) among relevant social groups. Qualitative data were collected through interviews, and major issues were analyzed using thematic analysis (TA).

As shown in Chapter 5.2, the interactions of social groups related to ESSs were analyzed using the main concepts (environment, organization, and cognitive or choice) of the organizational accident approach model by Vaughan (1999). However, as the ESS fire accident was not an independent event in one organization, it is difficult to use the concepts of the organization accident approach model. Therefore, an operational definition was provided based on the characteristics of the major social groups. The relevant social groups of the ESSs formed Technology-interest alliance. The structural feature of this alliance was the coalition of various social groups with interests, like some structural characteristics of the organizations. Accordingly, Technology-interest alliance was operationally defined as ESS organization. The interactions of the ESS organizations that contributed to the accidents were analyzed within the framework of the environment, organization, and cognition/choice.

The influence of the social context and culture were examined to understand social environment. The government's support policies and regulations impacted the use of ESSs by social groups. The REC weight of 5.0 affected the market entry of various companies and the rapid increase in ESS installations. The insufficient regulatory environment made it easy for relevant social groups to gain legitimacy and pursue economic interests within the regulation boundary. The social groups formed a power relationship each other. Electric control product manufacturers, centered on small and medium-sized enterprises (SMEs), were subordinated to battery manufacturers centered on large companies. It is suspected that this power relationship influenced the government's policy. For example, the ESS support policy was a government preference for creating demand for battery manufacturers. This cultural environment could have influenced the achievement of the goals of relevant social groups.

Cultures can influence each other with the dominant values and beliefs of major social groups. Battery and electrical control manufacturers are different groups and have different cultural characteristics. The cultural differences are as follows: There were differences in knowledge for each major in addition to the differences in disposition, perception of technology, and indifference to the other group's technical field. This cultural environment affected the social groups as an external factor and translated into the dominant values and beliefs of ESS organizations and members, and directly or indirectly affected ESS organization (Structure and Process) and members' behavior (Cognition/choice).

Technology-interest alliances reveal structural characteristics similar to organizational structures in that several relevant social groups were linked to pursuing their interests. It is the Structure of the alliance and the process in which RSGs' interactions occur. Cooperation is essential for manufacturers

in each field in the development and production of ESS products. ESS, which is tightly coupled to each other through such cooperation, could result in a fire in the entire system due to minor errors in the internal system. The structural separation that can distinguish manufacturers also causes communication problems between the battery and electric control manufacturers.

Inside of Technology-interest alliance, RSGs interact according to each social group's goal accomplishment. The benefits of government support policies have been designed to decrease gradually. The design of the gradual reduction of support policies acted as a deadline for social groups who desired economic incentives. The pressure to accomplish the goal for each social group resulted in the absence of an appropriate cooperation process, insufficient safety functions, and a lack of understanding of the technology in technological development. Consequently, large and small fire risks can accumulate and lead to fire accidents.

Finally, it is the cognition and choice of the ESS organization members. The behavior of the members can be primarily divided into risk disqualification, irrational choice of risk, and mistakes due to lack of expertise. Social groups' blind faith in battery technology manufactured by large companies led to the disqualification of fire risk and forced ESS organization members to use the system to achieve maximum economic benefits. For private power generation operators, chemical battery abuses such as overcharging and over-discharging occur because they perceive ESS as a means of pursuing additional economic incentives and do not recognize the technological risk. Additionally, the lack of expertise consequent of the short ESS development and commercialization period introduced human errors such as system installation errors and impacted the frequency of fire accidents.

Therefore, the interaction of related social groups created the following causes of fire: Several related social groups of ESS organizations were the cause of the fire directly or indirectly due to conflict and negotiation. The social context, cultural environment, limitations in the structure of cooperative, lack of awareness of fire hazards, and lack of expertise have been derived as the fire causes.

In Chapter 5.2, an exploratory approach was taken on the causes and significant issues of fire, focusing on socially constructed ESS technology. Before analyzing qualitative data through TA, SNA was performed to prevent the focus from being biased according to the researcher's subjectivity. Through this, it was possible to find the influence of government policies on the social construction of ESS technology, differences in perception of ESS fire accidents (causes and measures) according to Major and Fields, and ESS technology that has become a means of accomplishing the purpose. Notably, the social context and response of relevant social groups, the form of tight coupling with battery and electric control fields, the difference in majors and communication (different terms) problems, fire risk of the ESS, and utilization of ESS technology as Black box could be checked.

Based on the exploratory analysis results of 5.2, TA was conducted to approach the interview data in depth. As mentioned in Chapter 5.3, the critical issues revealed in the interviews were developed in one theme. The main causes of the fire were derived from interview materials. Based on this, the codes

were extracted, including social context, cultural environment, structure and limitations of ESS organizations, fire risk due to interaction, and lack of risk awareness and expertise. Finally, a theme was developed using the codes. The theme was Hidden causes of fire in Black box (ESS technology). The theme of the interview data was that the causes of ESS fires were not technical flaws but were caused by the conflicts and negotiation process of the social groups.

Notable analysis results in SNA are the differences in the semantic network structure of the battery and electrical control product manufacturers. Different perceptions of the ESS and fire accidents appeared in the battery and electric control fields due to differences in the majors. As mentioned in the Chapter 5.3, this difference is in the knowledge and perception of technology and members' personalities by major through TA. Additionally, the indifference to each other's fields is revealed in the network analysis. In the semantic network of battery and electric control manufacturer members, differences in terms used by Major and communication problems were revealed in the network. It was confirmed that workers in both fields recognized the other's domain as a different field. Therefore, the main issues of the interview data revealed through the semantic network structure were reflected in the TA's analysis process. Through this, it was possible to supplement the limitations of TA. The analysis results of Chapters 5.2 and 5.3 are summarized in the following figure.

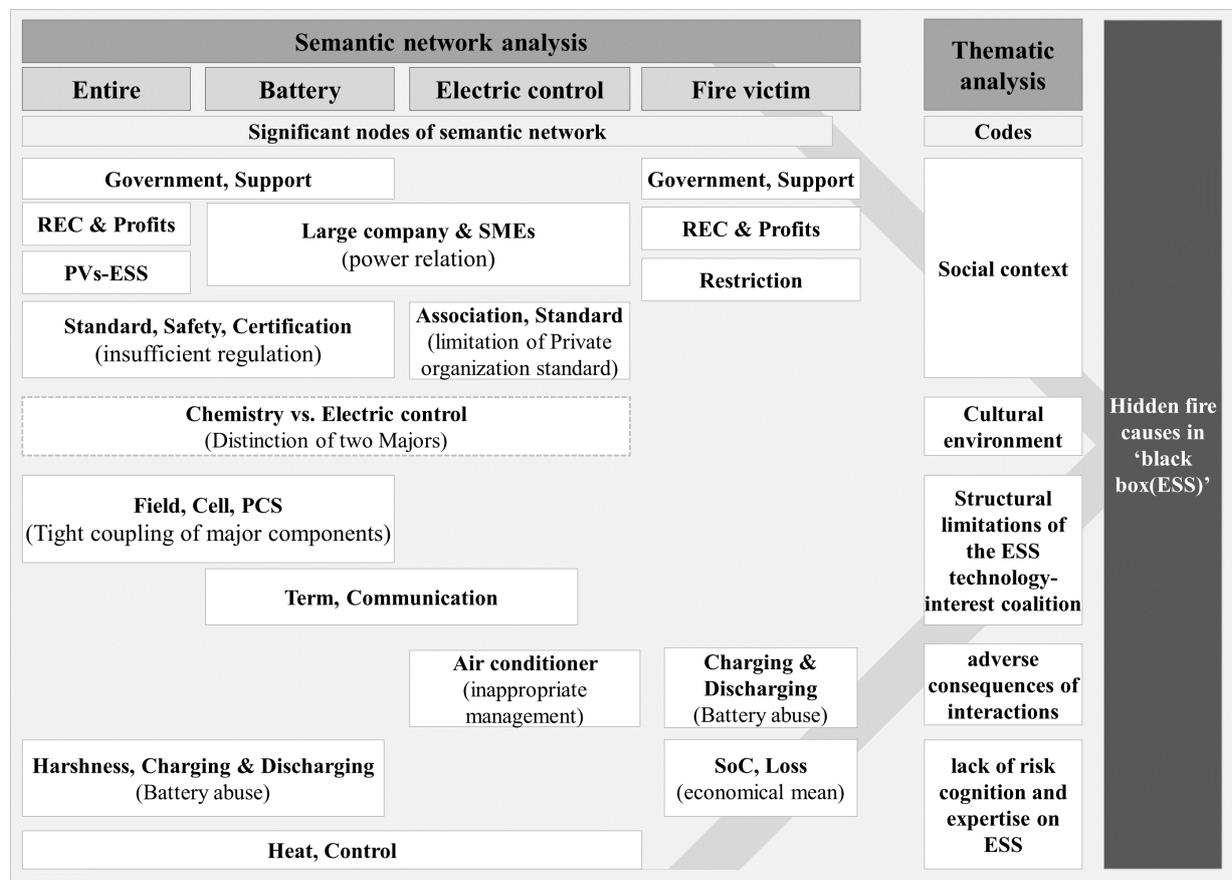


Figure 6.1 Analysis results of SNA & TA

A summary of these analyses is as follows: Through a literature analysis, the process of socially constructed ESS was examined. This analysis examines the government's support and regulatory policies and the behavioral choices of ESS manufacturers and users in response to them. The government's REC 5.0 support policy for ESSs led to a rapid expansion of the market, and it was confirmed that ESSs became a widely used technology by society. Technical artifacts were used by relevant social groups as a well-functioning technology without doubt than concerned with the inherent complexity of the technology. Thus, the ESS became a Black box.

However, as the fires broke out, the focus fell on the inherent technical complexity of the ESSs, and the conflicts and negotiations among social groups. Then, the Black box was opened and thoroughly reviewed. However, it is difficult to provide sufficient evidence from the literature on how social groups negotiated conflicts.

Therefore, TA was conducted using qualitative data collected through interviews. Based on the experiences and perceptions of ESS workers, the process of conflict and negotiation among social groups regarding the Black box was reviewed. Accordingly, the concepts of several accident approach models were defined operationally, and explanations of the process and results of the interaction of groups were presented. Within the framework of the accident approach model's concepts (environment, organization, and cognition/choice), the social context, culture, ESS organization, interaction among organizational members, and lack of awareness of fire risk surfaced and created major and minor issues. These were important issues that could also be identified through semantic network analysis.

6.2 Discussion

This dissertation considers the impact and risks that social factors may have on the risk of ESSs, which have rarely been considered in previous studies. Here, the impact and change of technology on society are considered than examining the ESS composition due to social influence. ESS, a technological artifact, had a great impact on society because of fire accidents. The fire risk of ESS has been well imprinted on experts from major social groups, users, and even the government. Accordingly, the government supplemented the ESS regulatory environment (MOTIE, 2020), and major ESS product manufacturers have added safety functions to the ESS (Kim, 2019b). However, despite these changes, the private power generation operators' views on ESS remain cold, and the ESS industry's growth has almost been suspended, compared to 2017 and 2018. For private power generation operators with negative perceptions, improving the reliability of ESSs can provide a starting point for reconfiguring the future direction of ESS development. Like this, this dissertation has both academic and policy significance.

Reviewing ESSs from the SCOT's perspective did not provide a sufficient explanation of how each group's profit-seeking actions occurred, whom they collided with, and their factors for negotiation.

Therefore, this study attempted to explain the conflicts and negotiation of social groups using the general concept of STS called the “Black box” and the main concepts of accident approach models that consider social factors (environment, organization, and behavior).

Relevant social groups adopt the final form of technology through conflict and negotiation. Relevant social groups are profit-seeking groups, and they engage in complex interactions (conflict and negotiation) according to their interests. ESSs are composed of alliances of several related social groups, and the details of the interaction were analyzed using concepts such as environment, organization, and behavior of the causes of fire accidents due to their interactions (conflict and negotiation). Particularly, it was possible to determine the causes that affected the fire accident, such as structural separation and communication problems that occurred in the form of the ESS organization and the occurrence of fire risks caused by insufficient risk perceptions among members of the organization.

Finally, the recognition of the Black box of social groups can provide a springboard for the future development direction of ESSs. The ESS was constructed through flexible interpretations, conflicts of interest, and the negotiation of social groups. It was adopted by social groups such as private power generation companies, resulting in rapid technological development. The ESS was like a Black box used without any doubt. The public perceives technology as a mean to pursue economic incentives rather than properly understanding new technologies. Such naive technology utilization and lack of awareness of risks is a motivation to mitigate and deter future technology risks, setting the development direction of ESSs, and applying new technologies according to social needs. Such academic results can provide a direction for improving ESSs. It presents the guide and clues for accepting new energy technology, an unavoidable topic for the public in energy transition technology. Bijker and Law (1994) highlight that socially constructed technology should contribute to society.

Policy significances are to supplement the limitations of existing investigations and redefine the direction of technology development as follows. This study presented the limitations of the existing government accident investigation and considered the influence of social factors to supplement it. Official accident investigation committees have limitations in that they focus only on technical defects that directly affected accidents and do not fully consider social and contextual factors (policy, economy, and culture) with the government's influence (Committee composition). This dissertation provides a complement to these limitations. Moreover, it aims to provide policy impacts and better usability of technology in reconfiguration the direction of technology development. In the process of energy transition, government policies on energy-related technologies may be important (Essletzbichler, 2012). For example, the policies for the spread of RE, such as the REC weight applied to the ESSs, were able to strengthen the market rapidly, but a technical failure such as series of fire accidents occurred as side effects.

Accordingly, policy proposals were presented using the concept of ‘Black box’ and ‘Usability’ reviewed in Chapter 2.4 in presenting the development direction of the ESS technology. Various social

factors influence the public's adoption of new technologies, and the final technology artifact constructed and adopted through this is accepted as a scientific fact and used without question or doubt. The technology that has become a Black box acts as a mean to users, reducing the need for technical understanding and focusing only on achieving the purpose. Thus, it is necessary to consider the usability engineering aspect discussed in chapter 2.4. Usability refers to users' degree of ease when utilizing certain technology. Currently, usability considers reducing the risk of human error while securing the convenience of technology. Specific technology should be designed, considering the performance and efficiency of a function, and such that people's mistakes or risks are avoided.

Therefore, new technologies, such as ESS, need to be considered with usability when accepted and utilized by the public. When a new technology is adopted by society and acts as a Black box, this usability can be more valuable. Relevant social groups use the technology that has become a Black box without considering the internal complexity and risk, leading to adverse outcomes. After all, technology is not all about enforcing safety. It is necessary to move in a direction where technology itself can be efficient and safe, considering usability and safety factors together.

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