Systems Analysis of the Impacts of Energy Supply Shortage in Kamaishi for Resilience Building after Great East Japan Earthquake

Takehiro Kawahara

Master Thesis Series in Environmental Studies and Sustainability Science,
No 2012:021

A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (30hp/credits)

LUCSUS
Lund University Centre for Sustainability Studies

Systems Analysis of the Impacts of Energy Supply Shortage in Kamaishi for Resilience Building after Great East Japan Earthquake

Takehiro Kawahara

A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science

Submitted May 15th, 2012

Supervisor: Deniz Koca, Chemical Engineering Department, Lund University

Abstract

The Great East Japan earthquake and tsunami hit coastal cities in Iwate, Miyagi and Fukushima Prefectures of Tohoku Region devastating the energy supply system in the region. Following electricity outage and fuel shortages caused severe problems in the city of Kamaishi varying from lack of mobility, communication, heating to reduced health conditions.

It is important to build resilience of communities in disaster-prone areas to cope with the problem, meaning that they are able to manage energy supply shortage for themselves right after natural disaster. Resilience building against natural disasters would contribute to sustain safety, sense of security, social connections and social institution of the communities. However, it requires of better understanding of the concept of resilience and the complex interactions in social - energy supply system.

This thesis, aims to analyze the impacts of the earthquake and the tsunami on local energy supply system in Kamaishi City by; i) clarifying what energy services were in need when there was a shortage in energy supply right after the disaster by performing semi-structured interviews; and ii) identifying and analyzing causes and effects of the energy supply shortage at local level when the disaster occurred by applying systems thinking and causal loop diagramming. Suggested alternative potential measures in tackling energy supply shortages and in preparing future disaster risk reduction plans from resilience perspective are expected to be use of both policy makers and individuals. Based on these works, the thesis makes an attempt of developing causal loop diagramming as learning tool and decision support tool to build resilience of communities against natural disasters.

Key Words: Earthquake, Tsunami, Natural Disaster, Energy system, Systems thinking, Systems analysis, Causal Loop Diagrams, Resilience

Acknowledgement

First of all, I would like to express my gratitude to my supervisor, Deniz Koca, who took a lot of his time for me and gave me many advices in writing the thesis. I also would like to express my thanks to LUCSUS staffs. They have been ambitious in education of sustainability and taught me the importance of thinking deeply and critically. Many thanks to my LUMES friends, whom I learned with, gave me a lot of inspirations.

I appreciate all the people in Kamaishi who gave me opportunity of interviewing. They gave me important information and insights for understanding the problem I addressed in the research. I also learned how it was important to have conversation with them to understand the problem as well as the tragic event in my hometown more deeply.

Many thanks to the Rotary International including District 2520 (Miyagi-Iwate), Kamaishi Rotary Club and Lund-Dalby Rotary Club, which supported my study and life in Lund. I especially would like to express thanks to my host counselor in Lund-Dalby Rotary Club, Bengt Löstad, and the leader of ambassadorial scholar's committee in District 2520, Hiroshi Hashiura.

I would like to thank to my former colleagues in Japan Science and Technology Agency (JST), especially those who worked with me in Research Institute of Science and Technology for Society (RISTEX). They understood my decision to study in Sweden and encouraged me. My starting point of learning sustainability science is in RISTEX.

I also would like to express thanks to some individuals. Yuko Harayama at Tohoku University, who helped me in preparing studying in Sweden and encouraged me. Masaru Yarime at University of Tokyo, who gave me advices in studying sustainability science. I thank to Asuka Uesaka at Lund University. I was always stimulated by her ambition and activities to support the affected people by the disaster in Tohoku Region. I thank to Petra Lang, who told me about life in Sweden and encouraged me since before coming to LUMES. I also thank to all my friends in Sweden, Philippines, Japan and other countries in the world, who encouraged me.

I appreciate Mong Sing Lai who understood my will to study sustainability science and supported me for years, and I also thank to her all family and relatives in Malaysia. Finally, I would like to say thank you to my parents and brother, who understood my will of studying in Sweden and supported me for long time.

Takehiro Kawahara, 15th May, 2012

Table of Contents

List of Figures

List of Tables

List of Abbreviations

CLD Causal Loop Diagrams
DG Distributed Generation
EV Electric Vehicle
IPP Independent Power Producer
LPG Liquefied Petroleum Gas
PHEV Plug-in Hybrid Electric Vehicle
RQ Research Question
TOHOKU-EPCO Tohoku Electric Power Corporation

1. Introduction

1.1 Background: The Great East Japan Earthquake

An earthquake of magnitude 9.0 generating a massive tsunami hit north-eastern Japan on 11th March, 2011 (Hosomi 2011, 415). Coastal cities in Iwate, Miyagi and Fukushima Prefecture of Tohoku Region (Figure 1) were devastated by this natural disaster with 15,854 deaths and 3,155 missing (as of 14th March, 2012) (Japan. National Police Agency of Japan 2012). The earthquake and tsunami unveiled the vulnerability of the current energy supply system that all the affected cities relied upon. Energy supply was insufficient in the affected areas after the disaster due to electricity outage and shortage in fuel supply such as heating oil and gasoline (Japan. ANRE 2011a). About 30% of the population in the affected areas was over 65 years old and many of those who could flee from the tsunami battled for survival in the condition with insufficient heating in the severe cold weather in Tohoku Region (McCurry 2011). The electricity loss was a vital problem for patients in the hospitals as they needed it for medical devices (Sasahara 2011). It was also critical that communication lines were stopped, which made it difficult to access to vital information (Nohara 2011). Days took for restoration of electricity outage and recovery of fuel supplies (i.e. gasoline, light oil, etc.) varied with areas. It took at least a few days to recover electricity supply even in not directly affected areas and several days to start transporting oil to the affected cities at large scale from the western Japan (Japan.ANRE 2011a). Therefore, the first several days after the earthquake and tsunami were quite vital period for the affected communities in Tohoku Region with self-reliance to cope with the problem for survival. Kamaishi, the small coastal city in Iwate Prefecture, is one of the cities experience such a problem.

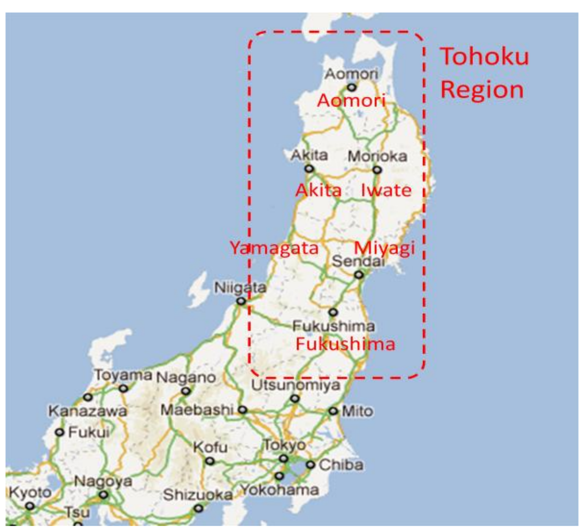


Figure 1. Map of Tohoku Region (Google Map)

1.2 Problem: Energy Supply Shortage

The earthquake and tsunami caused electricity outage and fuel supply shortages, which affected the communities in Tohoku Region. The causalities and the situation are discussed in detail below.

1.2.1 Electricity Outage in Tohoku Region

Tohoku Region has 6 prefectures: Aomori, Akita, Iwate, Miyagi, Yamagata and Fukushima. All the prefectures experienced electricity outage except for some areas in Fukushima Prefecture regardless whether the tsunami hit or not. Figure 2 shows the electricity generation plants belonging to Tohoku Electric Power Corporation (TOHOKU-EPCO). Niigata Prefecture is not a part of Tohoku Region, but there are 2 plants belonging to TOHOKU-EPCO. All the plants except for the 2 plants in Niigata stopped automatically for safety reason (Personal communication with Yurtec Corporation). There were also other plants such as IPP (Independent Power Producer) (e.g. Kamaishi Steel Works Coal-Thermal Plant)) shut down. The earthquake damaged the transmission substations and the transmission lines[1]. Some plants alongside of the Pacific coast were directly damaged by the tsunami (i.e. Haramachi Thermal Plant) (Japan.METI 2011a). Besides, distribution networks in coastal areas in Iwate, Miyagi and Fukushima Prefecture were hugely damaged by the tsunami (METI 2011a), which varied the restoration speed from location to location. 80% of electricity supply was restored within 3 days and 94% within 8 days after the disaster[2] (Figure 3).

[1] Transformer bushing, disconnecting switch insulator for substations and support insulator were damaged, which caused many short circuit and ground fault at the same time nearby the Miyagi transmission substation that connected to the 500kV and 270kV transmission lines. Therefore, the 500kV/270kV electric transformer and the 270kV transmission lines connected to Aomori, Akira, Iwate and Yamagata Prefecture were shut down (METI 2011a).

[2] These include areas where restoration work was not physically possible (METI 2011a). In Kamaishi, inland areas where the tsunami did not hit restored electricity supply earlier, whereas areas nearby the coast took longer time because of restoring the distribution networks.

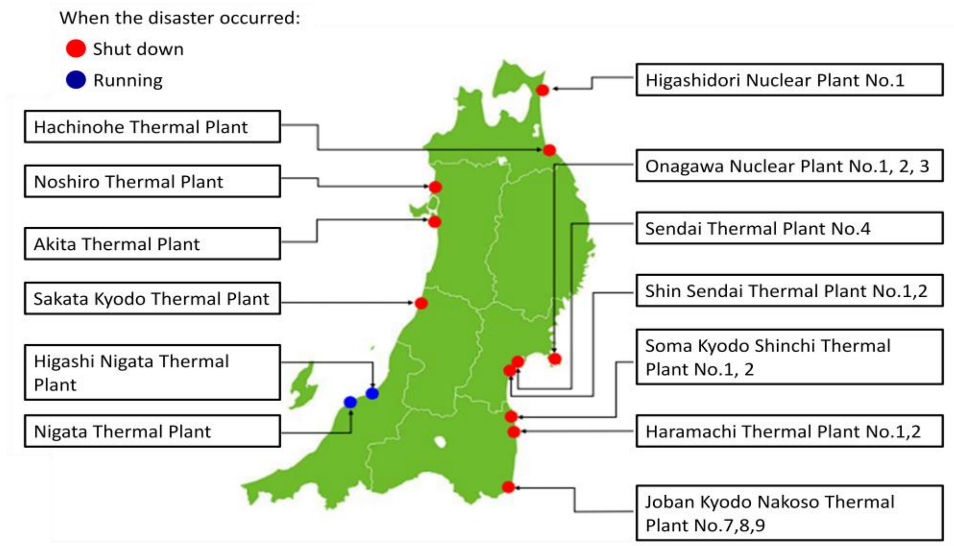


Figure 2. Electricity generation plants of TOHOKU-EPCO (Adopted from (METI 2011a))

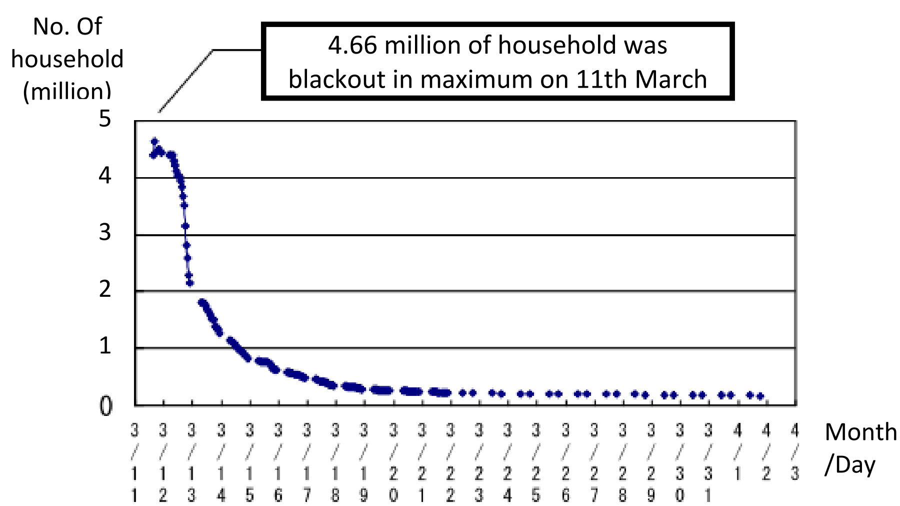


Figure 3. Number of households with blackout (Adopted from (METI 2011a))

1.2.2 Fuel Supply Shortage in Tohoku Region

As the disaster affected the fuel supply chain from local suppliers to large-scale infrastructures, there were gas and oil products shortages in Tohoku Region. The causalities and the general situation are discussed more in detail below.

1.2.2.1 Gas (LPG (Liquid Petroleum Gas) and Town Gas)

Table 1 shows how many LPG suppliers at local level and household LPG users were damaged by the tsunami. In addition to these local LPG suppliers, some of the main supply infrastructures (e.g. Sendai Gas Terminal) were also damaged by the tsunami. Electricity outage and communication loss also hugely affected the supply chain, for instance, filling LPG into cylinders[3] and communicating with other actors on the supply chain. Overall, LPG supply to hospitals and shelters by suppliers was started 4-7 days after the disaster.

Table 1. Number of LPG suppliers and household users in Tohoku Region and Kamaishi City
Adopted from (Advisory Committee on Energy and Natural Resources 2012) and (Mizuho Information and Research Institute 2012)

	# of LPG suppliers	**# of household LPG users**	**# of damaged LPG suppliers (%)**	**# of damaged household LPG users (%)[4]**
Tohoku Region	2,783	21,389,410	328 (11.79%)	141,044 (0.66%)
Kamaishi City	20[5]	14,180	17 (85%)	6,268 (44.2%)

Approximately 420,000 households had town gas supply stopped in Tohoku Region, and the majority was in Miyagi Prefecture whereas most of the households in Iwate and Fukushima Prefecture used LPG. It took until 3rd May to restore the town gas supply in Miyagi Prefecture because of repairing and safety check of the gas pipeline networks (Mizuho Information and Research Institute 2012, 15).

1.2.2.2 Oil Products (Gasoline, light oil, heating oil)

Oil supply was also in severe shortage in Tohoku Region. As shown in Figure 4, the oil bases on the Pacific side including Sendai Oil Refinery and Shiogama Oil Tank Facility in Miyagi Prefecture were damaged by the earthquake and tsunami. Overall, 30% of oil refinery capacity of Japan was lost for a while. The port and road infrastructures, tankers and gas stations were also devastated. Thus, right after the disaster, as emergency response, oil products were supplied from the oil bases on Sea of Japan side and Kanto Region to the affected areas (i.e hospitals, police) (ANRE 2011b). Several measures were taken to cope with the shortage around 7 days after the disaster. The national government ordered the oil companies to increase running rate of the oil refinery bases in the western Japan and transport oil products to Tohoku Region on 17th March. Shiogama Oil Tank facility was restored and it restarted shipping oil

[3] One of the filling stations in Kamaishi could supply LPG since there was an emergency electricity generator (Mizuho Information and Research Institute 2012, 5-6).
[4] Those who needed to evacuate from the nuclear accident in Fukushima Prefecture are also included
[5] It means 3 filling stations and 17 sales offices. 1 filling station and 16 sales offices were damaged by the tsunami.

products on 19th March (ANRE 2011a). Oil supply shortage recovered little by little in most of the areas since the early April (ANRE 2011b).

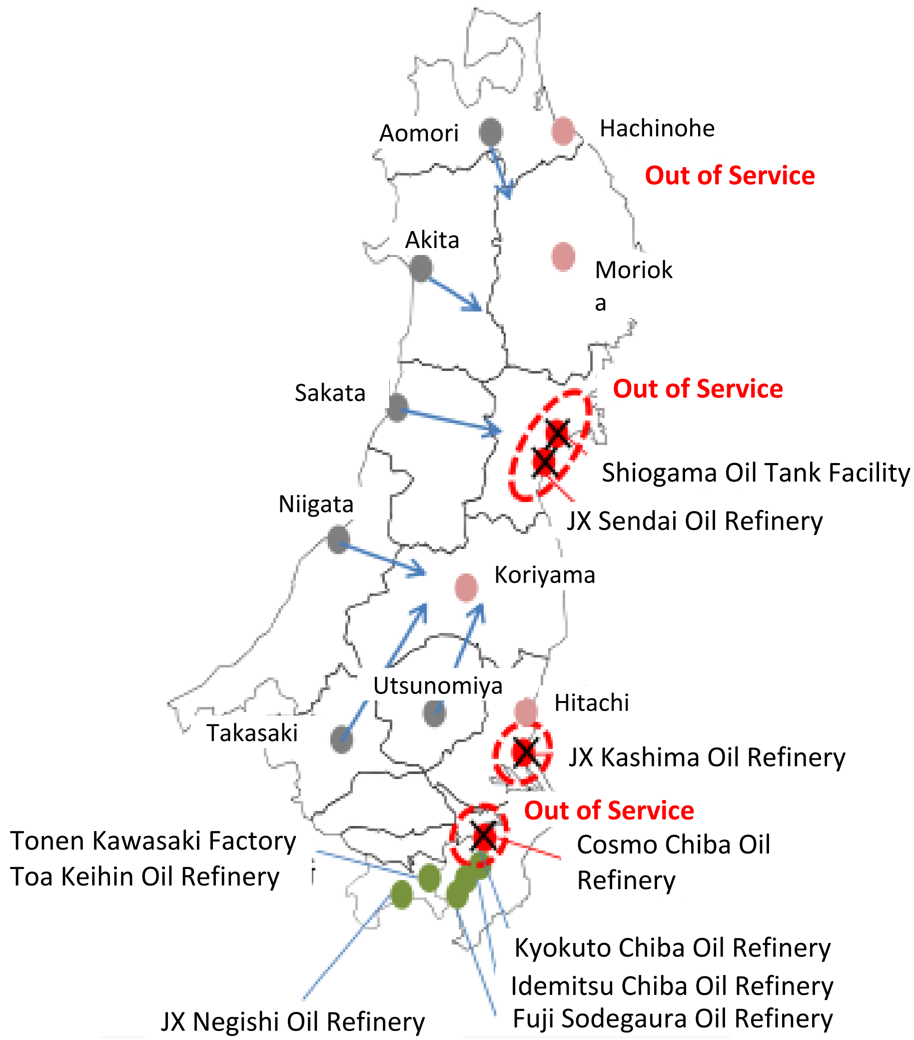


Figure 4. Oil supply system right after the disaster (Adopted from (ANRE 2011b))

1.3 Objectives

Overall objective of this thesis is to analyze the impacts of energy supply shortage in Kamaishi City in Iwate Prefecture to build resilience. More specifically, the objectives are:

(1) to clarify what energy services were in need when there was a shortage in energy supply right after the disaster by performing semi-structured interviews;

(2) to identify and analyze causes and effects of the energy supply shortage at local level after the disaster by applying systems thinking and causal loop diagramming;

(3) to suggest alternative potential measures for tackling energy supply shortages in preparing future disaster risk reduction plans from the resilience perspective, which could be use of policy makers and individuals; and

(4) to develop and demonstrate causal loop diagrams as learning tool and decision support tool to build resilience of communities against natural disasters.

1.4 Research Questions

The thesis addresses the following research questions (RQ) in order to achieve above objectives.

(1) What energy services were in need in the phase of response after the earthquake and tsunami hit Kamaishi?

(2) What were the causes and effects of energy supply shortages on individuals and the organizations in Kamaishi?

(3) What alternative measures potentially reduce the risk of energy supply shortage when natural disaster hit?

(4) How causal loop diagramming can support social learning and making decisions to build resilience of communities against natural disasters?

1.5 Rationales of the Research

1.5.1 Tackle the Problem of Energy Supply Shortage to Prepare for Natural Disasters

It is important to improve measures to tackle the problem of energy supply shortage at both policy and individual level to prepare for future natural disasters. No matter how efficient relief supply systems or robust electricity supply networks are established, it still takes time till enough relief supplies from other locations reach affected people after natural disaster. Such a problem is vital in disaster response (Chinese Taipei. MOEA 2001) especially in the areas frequently experience earthquakes and tsunami such as Sanriku Coast[6] including Kamaishi and other countries in Pacific "Ring of Fire" region (e.g. the US, Chile) (NTHMP Steering Committee 2001, 5). The outputs of the research should provide useful information and knowledge to such areas.

1.5.2 Reflect the Resilience Perspective to the Energy System Reformation in Japan

The concept of resilience should be taken into consideration of the energy system reformation in Japan. Several energy issues including vulnerability of the energy supply systems, energy security and safety issues of nuclear power plants, have been discussed at national level since the nuclear plant accident in

[6] Located in the north of Sendai City in northeastern Japan, and is formed with many steep and narrow bays. When wave starts to approach land, its energy that spread over the entire depth in the ocean squeezes into a shallow layer. This compression increases the amplitude of tsunami especially when it comes to narrow inlets (Witze 2012, 22)

Fukushima Prefecture (ANRE 2011a). The results from this research can provide insights into discussions of the issues of energy systems vulnerability.

1.5.3 Analyze Complex Social – Energy Supply System Interactions to Build Resilience

Building resilience of communities against natural disasters requires of better understanding of the concept of resilience and the complex interactions in social – energy supply system. Firstly, the concept of resilience is widely accepted as a means of adapting to global change, but it has been used without questioning what it means exactly. This has resulted in lack of recognition involved "in the politics and a tendency to under-emphasize the complexities enmeshed in realizing resilience in practice". Secondly, understanding disaster risk should focus on interrelations amongst the social vulnerabilities associated with different forms of disaster (Tweed and Walker 2011). In this respect, interdisciplinary study with systems thinking can provide the necessary understanding and knowledge of disaster risk.

1.5.4 Sustainable Development and Sustainability Science

Building resilience of communities against earthquake and tsunami would contribute to sustainable development in both practice and theory. Within the context of the problem, what need to be sustained are safety, sense of security, social connections and social institution. These are parts of social sustainability, which is defined as "a life-enhancing condition within communities, and a process within communities that can achieve that condition (McKenzie 2004, 12)". Building resilience can contribute to sustaining or enhancing those aspects. Relation between resilience building in Kamaishi against earthquake and tsunami and sustainable development is discussed further in Section 4.5. From the sustainability science viewpoint, there is a need of understanding complex interactions between the nature and society, applying systems thinking, and of bridging the resilience theory to practice. The concept of sustainable development and sustainability science are further discussed in Section 2.1.

1.6 Outline of the Thesis

The thesis consists of the 5 chapters (Figure 5). Chapter 1 mainly provides the background of the problem and the objectives, the research questions and rationales. In Chapter 2 starts with the discussion of the concept of sustainable development and ´sustainability science´, and the features of sustainability science in this research. Systems thinking and systems analysis as research methodology, epistemological and ontological considerations, and the research methods are explained. Chapter 3 provides theoretical framework of resilience that has evolved in ecology after discussing several definitions of the concept and similar terms. Chapter 4 is the core part of this thesis; results of semi-structured interview with 97 residents in Kamaishi and some organizations are provided. Causal loop diagramming method is applied to the results from both the literatures and the interviews, and then the causes, impacts and feedbacks of energy supply shortage in Kamaishi are identified and analyzed. Besides, alternative potential measures to tackle the problem are analyzed. Based on all the analysis results, theoretical discussions and recommendations to Kamaishi for resilience building against natural disasters are given. Chapter 5 concludes with important findings of the research and necessity for further research.

Figure 5. Thesis flow

2. Methodology and Methods

2.1 Research as Sustainability Science

The concept of sustainable development has emerged since the late 1980s due to the rise of the concerns in meeting fundamental human needs while preserving life-support systems of the earth (Martens 2006, 1). Sustainable development was defined as 'development that meets the needs of current generations without compromising the ability of future generation to meet their own needs' by the World Commission on Environment and Development in 1987 (WCED 1987). There are two fundamental issues here: Environmental degradation accompanied with economic growth, and yet there is need of growth to alleviate poverty (Sharachchandra 1991). Since then, sustainable development became the guiding theme in much of environmental literatures and one of the most important agenda of global affairs (e.g. the United Nations Conference on Environment and Development in Rio (1992), the World Summit on Sustainable Development in Johannesburg (2002)) (Sen 2004). The concept has evolved in the past a few decades, and sustainability thinking became the idea of three dimensions: Environmental, social and economic sustainability (IUCN 2006).

Scientists engaged societal and political process in shaping sustainable development agenda as discussion of how science and technology could contribute to sustainable development became increasingly important since the late 1980s (Kates et al. 2001, 641). In the process, there was recognition that understanding of behavior of the nature-society systems themselves and their complexity cannot be achieved with only understanding individual components of the systems (Clark and Dickson 2003, 8059). As a result, a new form of science – 'sustainability science' - aiming at understanding the fundamental characters of interactions between nature and society that would support decision making for sustainable transition has emerged (America 1999; Kates et al. 2001).

Sustainability science is not yet an autonomous discipline, but rather a vibrant area that brings together theory and practice, and different disciplines across the natural and social sciences (Clark and Dickson 2003, 8060). Sustainability science cannot be separated from the fundamental values of sustainable development, intragenerational equity and intergenerational equity. Today, there is a wide range of issues focused on in research projects of sustainability science, which are not limited to the range of the original concept above[7].

Although definition of sustainability science is not clear, there are fundamental features that are commonly known (Martens 2006). Sustainability science employs the form of science called 'mode-2', of which research projects are problem-driven or demand driven. Mode-2 science has features of transdisciplinarity, heterogeneity, transient and more socially accountable and reflexive than Mode-1. Mode-1 science is identical to what is meant science in general, which has the characteristics of single disciplinarity, being governed by academia, homogeneity and hierarchical (Gibbons et al. 1994) (Table 2). As research of sustainability science aim at not only creating useful knowledge through action but also at generalizing them to be applied to other problems, they are characterized as 'use-inspired research' ('Pasteur's Quadrant') (Stokes 1997). Thus, it is neither applied research ('Bohr's Quadrant') nor basic research ('Edison's Quadrant'). Scientific knowledge from a diverse range of disciplines including both natural and social science are applied, and knowledge is coproduced by collaboration between scientists, policymakers and citizens (Martens 2006, 38). Since problems dealt with in sustainability science are dynamic and complex, a systems perspective and systems science have role to play in order to understand interrelations between causes and effects of such complex problems (Hjorth and Bagheri 2006).

Table 2. Properties of Mode-1 and Mode-2 Science (Martens 2006, 38)

Mode-1 science	**Mode-2 science**
Academic	Academic and social
Mono-disciplinary	Trans- and interdisciplinary
Technocratic	Participative
Certain	Uncertain
Predictive	Exploratory

There are some features of sustainability science embedded in this research (Figure 6). The research is driven by the problem of energy supply shortage caused by the earthquake and tsunami on 11th March,

[7] In addition to this, for instance, Integrated Research System for Sustainability Science (IR3S) at University of Tokyo suggests the concept of sustainability science through the lens of three levels of system at global, social, and human, which are crucial to the coexistence of humans and the environment (Komiyama and Takeuchi 2006, 2). Sustainability issues often arise from interactions between these three systems, thus holistic approach to identification of problems is crucial.

2011, which affected people's quality of life. It is an interdisciplinary research, thus, knowledge from different disciplines such as disaster risk management, ecology, energy technologies, systems science are applied for knowledge production. Systems thinking is employed to understand the complexity of the problem holistically and to find leverages to make change of it. The research is on the position of Pasteur's Quadrant because it aims at not only understanding the problem and proposing potential measures to tackle the problem, but is also generalizing findings to be transferred to other problems (use of resilience theory for disaster risk management, causal loop diagram as social learning tool for resilience building). The knowledge (output) is expected to contribute to increasing social aspects of sustainability. The research outcome is expected to enhance social sustainability such as safety, sense of security and social connections of people living in disaster-prone areas for the future generations' well-being.

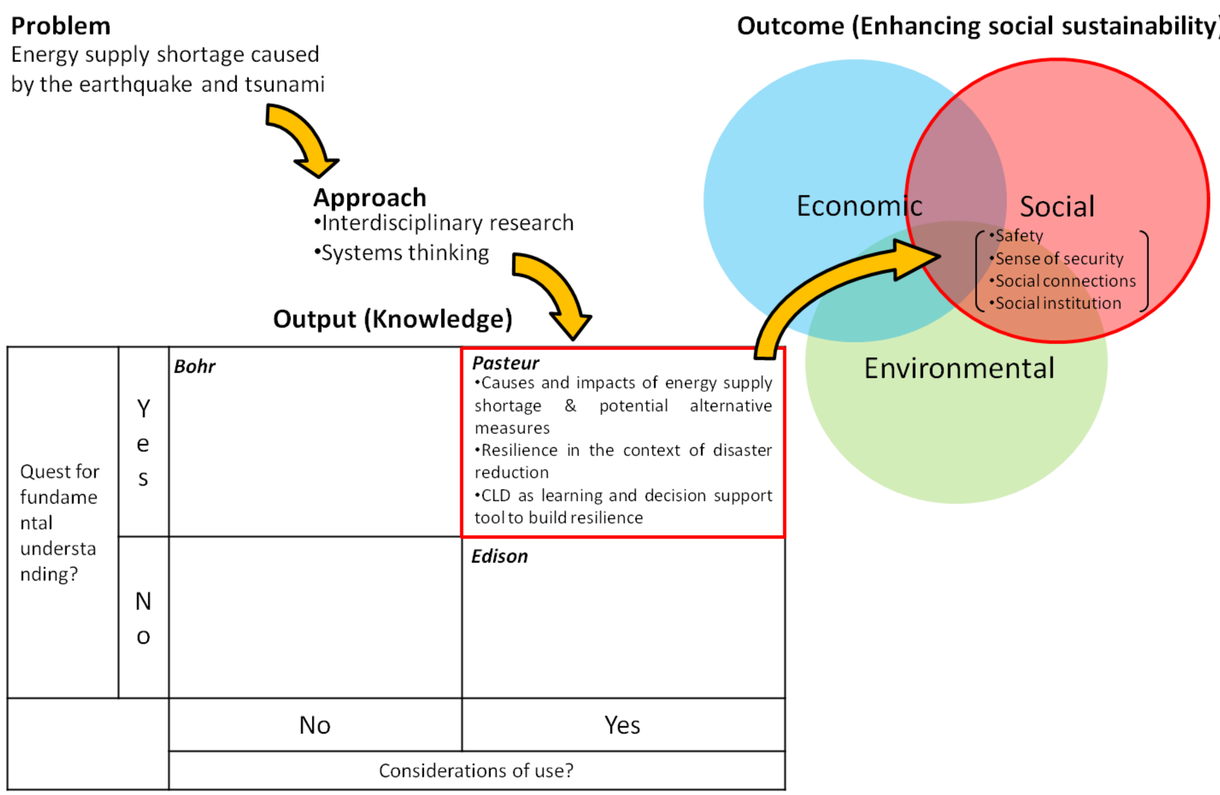


Figure 6. Research as sustainability science (Adopted from Stokes (1997) and ICUN (2006)

2.2 Systems Thinking and Systems Analysis

A system is defined as "an interconnected set of elements that is coherently organized in a way that achieves something", which "consists of elements, interconnections, and a function or purpose (Meadow 2009, 11)." The system's response to external forces, which is often complex in the real world, is characteristics of itself (Meadow 2009, 2). Systems thinking is "the mindset and philosophy of thinking about whole worlds instead of symptoms and event sequences (Haraldsson 2005, 1).” It aims to understand complex issues by highlighting interactions, identifying root causes of problems and seeing new opportunities in our world that is changing and complex, in order to provide integrated strategies to address them in a practical manner (Hjorth and Bagheri 2006; Koca 2008; Meadow 2009, 2). Systems analysis is a practical approach of systems thinking[8], which is “taking apart of these worlds to understand the causalities, detect and discover their structural arrangement and understand the effects emerging from the flows and accumulations from the causalities acting in the systems (Haraldsson 2005, 2).”

The reason why understanding of systems characteristics is necessary is because “humans cannot act without recognition”, which means that elements of systems, even though they are small but may affect the characteristics, are often out of our recognition without holistic understanding of systems (Nishimura 2004, 149). Maani and Cavana (2000, 13) propose ‘four levels of thinking’ which consists of events, patterns, systemic structures and mental models from the top of an iceberg (Figure 7). Events are just what happened and people are satisfied with information at this level mostly. Patterns of the events provide a richer picture of how the events happened with more insight into the ‘story’. At the level of systemic structures, different factors interact and bring about the outcomes that we observe. But it is rare to see how such patterns relate to one another without much deeper thinking. The deepest level is mental models of individuals or organizations, which are based on the beliefs, values and assumptions that we have. These influence reasons why things do or do not work.

[8] Another approach is system dynamics, which is “the use of the results of System Analysis in order to reconstruct the system of causalities (Haraldsson 2005, 1)” to understand behavior of the system over time (Koca 2008). The result of systems analysis is transferred into dynamic numerical model (Koca 2008) to assess the performance of reproducing the events and histories of the system and to predict future behavior (Forrester, 1961)” But, the thesis does not utilize this approach since it needs quantitative data that were not obtained.

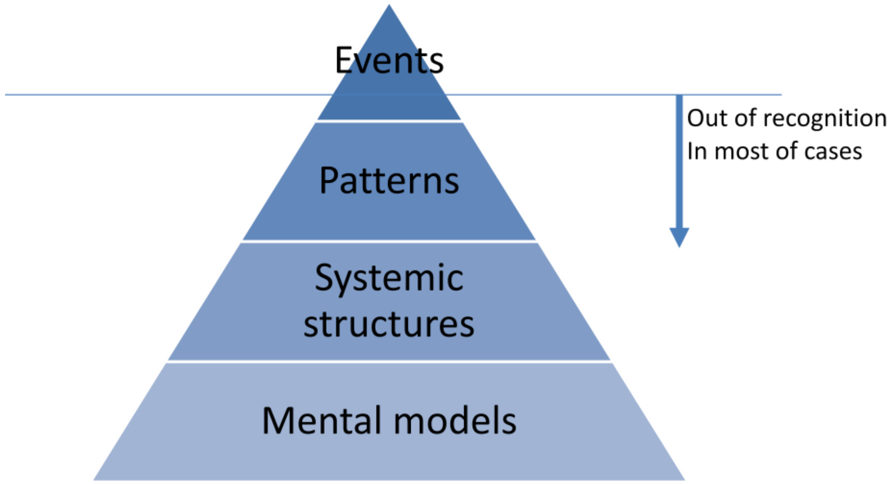


Figure 7. Four levels of thinking (Maani and Cavana 2000)

Resilience is hard to see without whole-system view (Meadow 2009, 77). In the context of the problem, without understanding impacts of energy supply shortage and behavior of the affected people in a holistic manner, it is hard to know what actions are needed to cope with the problem more effectively to prepare for future disasters. Systems thinking and systems analysis help us seeing "leverage point" to create intervention strategies in disaster risk management. Leverage here means "actions or interventions that can have a lasting impact on the system in terms of reversing a trend or breaking a vicious cycle" (Maani and Cavana 2000, 37). In this study, systems thinking and systems analysis help stakeholders to recognize and understand causes, effects, feedbacks and how these systems are interrelated for taking proper actions for residence building.

2.3 Research Design and Methods

This research was carried out with both quantitative and qualitative methods, called "mixed method research" (Bryman 2008, 603). The methods used in the research varied with research questions. The research employed triangulation that implies "using more than one method or source of data in the study of social phenomena (Bryman 2008, 379)". The aim to conduct mixed method research is that "the results of an investigation associated with one research strategy are cross-checked against the results of using a method associated with other research strategy" for each research question (Bryman 2008, 611). For instance, data of causes and impacts of energy supply shortage were cross-checked from both literatures and semi-structured interview.

Table 3. Research methods corresponding to the research questions

Research Questions	Research Methods
(1) What energy services were in need in the phase of response after the earthquake and tsunami hit Kamaishi?	Literature review, Social Survey (Semi-structured interview, Coding)
(2) What were the causes and effects of energy supply shortages on individuals and the organizations in Kamaishi?	Causal loop diagramming
(3) What alternative measures potentially reduce the risk of energy supply shortage when natural disaster hit?	Causal loop diagramming, Literature review
(4) How causal loop diagramming can support social learning and making decisions to build resilience of communities against natural disasters?	(Participatory approach for social learning by using CLD is suggested in theoretical discussion, but not conducted in this research.)

2.3.1 Literature Review

Literature review is carried out to know what is already known about the relevant areas of this research, and to develop the arguments and the analytical frameworks (Bryman 2008, 81). First of all, literature review through the articles, governmental reports and other web-based materials was conducted to understand the fact of energy supply shortage and the restoration, and to collect empirical data of energy services in need (RQ(1)). Articles of resilience theory were reviewed in order to discuss the concept's definition and issues of its application, which were the base of the analytical framework for RQ(2), (3) and (4). Literature of energy technologies were reviewed to analyze potential alternative measures of energy supply shortage (RQ(3)).

2.3.2 Social Survey

Social survey is ”a cross-sectional design in relation to which data are collected predominantly by…structured interview on more than one case” and ”at a single point in time in order to collect a body of quantitative or quantifiable data in connection with two or more variables.“ The objective of social survey is to detect patterns of relations between variables (Bryman 2008, 699). The social survey was consisted of stratified random sampling, semi-structured interview and coding. To address RQ(1), the three areas (Toni-cho, Unosumai-cho, Tenjin-cho) severely affected were selected in order to see the difference amongst them, and the 97 residents were randomly visited and given semi-structured interview one by one (see 2.3.3 for more detail of semi-structured interview). This type of sampling is called stratified random sampling, in which "units are randomly sampled from a population that has been divided into strata (Bryman 2000, 699)." The 97 residents out of 37,617 in April, 2012 (Kamaishi City ibida), which is only 0.26% of the total population in Kamaishi. But, it was considered that the sampling number was large enough to show the tendency of the coastal communities because: i) the population living in the coastal areas is 16,749 (42.87%)[9], thus the rate of the interviewees per the total population is 0.56%, and ii) it was assumed that some areas had similar tendency in terms of impacts of energy supply shortage, therefore, choosing only the three areas would not largely affect the results. The responses for each question were unstructured form; therefore they were coded in order to quantify (Bryman 2008, 233). All the responses and the quantified data are given in Appendix A. See the Section 4.2 for more detail of the interviews and coding.

2.3.3 Semi-structured Interviews

There were two types of semi-structured interview in this research. First type is the one with the 97 residents, which was a part of the social survey (see 2.3.2) and was conducted in Kamaishi from 10th to 16th February, 2012. The aim of this semi-structured interview was to understand the impacts of energy supply shortage on their life right after the disaster. Ethical principles were considered when conducting the interviews especially because there was possibility to harm the interviewees psychologically by asking questions about the tragic event. The interviewees were given much information such as who the interviewer was (also the ID card with photo and home address hanged from the neck), where the interviewer came from (emphasized that he came from the same city, which might be important for trust building) and the objectives of the interviews. They could choose whether they participate in or not before the questions were asked. Individuals are not identifiable from their answers as well as the data

[9] Data of population in each district in April 2012 were not available. Therefore, the population in the coastal areas (Kamaishi District, Unosumai District, Heita District and Toni District) was calculated based on the statistics in November, 2011 (Kamaishi City 2011). The total population excluding deaths and missing persons was 39,065 and that in the coastal areas was 16,749 (Assumed that only the half of residents in Heita District lived in the coastal areas because the rest lived at high point and far enough from the coast.)

published. Respondent variation was not conducted for these interviews because it was practically difficult due to no contact information and limited time.

Another type of semi-structured interview was conducted with the three organizations in Kamaishi, which was independent of the social survey (See Appendix C for the questionnaires). Kamaishi Works of Nippon Steel Cooperation was interviewed on 9th February, 2012, to understand the impacts of energy supply shortage on their activities and facilities. Kamaishi Branch Office of Yurtec Cooperation was interviewed on 13th February, 2012, to ask about the causes and the restoration process of the electricity outage. The company is a child company of Tohoku Electric Power Corporation, which was in charge of restoring the electricity supply infrastructures in Tohoku Region. Kamaishi Works plays an important role in Kamaishi's manufacturing industry and owns the coal-thermal plant as IPP. Thus it was considered important to discuss the impacts on their activities and facilities as well as the role of their plant in electricity supply in the future. The interview with Steel Memorial Hospital was conducted on 16th February, 2012, because impacts of energy shortage on medical services were considered vital as electricity is required for medical devices use and heating for patients.

2.3.4 Causal Loop Diagramming (CLD)

A causal loop diagram (CLD) is a tool for revealing the causes and effects relationship among a set of variables operating in a system. CLDs consist of variables and arrows, basically. A variable can be both quantitative (if measureable) and qualitative. An arrow indicates represents a causal relation between two variables. Causal relationships indicated by '+' mean positive correlation in the same direction, while those indicated by '-' mean negative (Figure 8). The strength of a CLD is that it provides readers the whole-system view and a framework for seeing interrelationships rather than things (Senge 1990, 8). CLD also has the ability to incorporate qualitative variables in systems thinking (Maani and Cavana 2000, 26). But, since it does not express quantitative information (i.e. cooperation between neighbors), in order to analyze the behavior of systems over time, systems dynamics approach is needed.

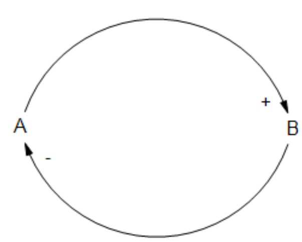


Figure 8. Causal loop diagram

CLD was used as a tool to analyze causes, impacts and feedbacks in the society – energy supply system when the energy system was disturbed by the disaster (RQ(2)), and potential alternative measures were analyzed (RQ(3)). The CLDs were developed based on the qualitative data gained from the relevant literature and the social survey.

2.4 Limitations of the Research

There are some limitations of the research. The first limitation lies in the sampling of the social survey, in which the sampled interviewees might be biased at certain level. Although units from the population were randomly sampled, attributes of the interviewees (e.g. gender, age) might be dependent on the timing of interview and custom in their family. The second limitation is in the semi-structured interviews with residents and organizations. Although the primary objective of the research is to analyze the impacts of energy supply shortage to build resilience by understanding what energy services were in need, social aspects (e.g. cooperation within a community, preparation by the municipality for energy supply shortage) which could affect the impacts were also significant to analyze for resilience building. However, questions for the residents to understand social aspects were limited during the field work and some key organizations (e.g. municipality) were not interviewed. These were because of more findings came up after the field work, limited time, and limited financial resource to conduct another field work. The fourth limitation is showing quantitative data of the impacts of energy supply shortage and potential alternative impacts. Because quantitative data for each variable were not obtained or measured, it was not possible to assess the systems characteristics quantitatively (in this research, weather the system is resilient or not). The fifth limitation is in testing of the CLD that shows the potential alternative measures to tackle energy supply shortage. Differently from the CLD that shows the causes and impacts of energy supply shortage, which is somehow validated as it represents the interviewees opinions, the CLD showing potential measures is based on information from the literature and knowledge of the author, hence it is not validated. Whether the suggested measures are technically and economically feasible to be implemented lies outside the scope of this thesis and it requires further participatory group modeling.

3. Theoretical Background: Resilience

3.1 Resilience Theory in Disaster Risk Management

The capacity of affected community by disasters to survive, adapt and bounce back with a little or no assistance has been increasingly focused in the past a few decades. The capacity building of these communities requires stronger emphasis of resilience on risk reduction approach (IFRC 2004, 11). The adaptation of the Hyogo Framework for Action 2005-2015 made a big step to this movement (Manyena 2006, 434), of which one of the strategic goals emphasizes the development of institutions at community level that can systematically contribute to building resilience to disasters (UNISDR 2005). UNISDR (2009) defines resilience as:

> "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions."

Resilience is an important concept in the context of disaster risk reduction because: Firstly, it helps us shifting our perspective to another; not that future natural disasters are expected, but they will be unexpected. This perspective does not require a capacity to predict the future, but a qualitative capacity to device systems that can accommodate future disasters that may take place unexpectedly (Holling 1973, 21). Secondly, activities to build resilience against natural disasters can be helpful for communities to enhance their capacity and livelihoods, allowing them to make appropriate choices within the context of their environments (Manyena 2006, 436). Thirdly, the concept helps understanding risks of disaster in a comprehensive manner and estimating them by multi-disciplinary basis. It is necessary to be aware of not only physical damage and economic loss but also social, organizational and institutional damage. Unfortunately, risks generally have been estimated in different disciplinary approach, but not conseptualised from a holistic perspective (Manyena 2006, 436).

The definitions of resilience diverge across different disciplines in reality and there is no consensus on its definition as well as its application (Klein et al. 2003, 39). Since resilience is used as analytical framework to analyze impacts of energy supply shortage and to find potential alternative approaches to the problem, its definition and elements need to be clarified in the context of the problem.

3.2 Different Definitions of Resilience

3.2.1 Two Dominant Definitions of Resilience from Ecology

The study of resilience has originally evolved in the field of psychology and psychiatry in the 1940s, in which the researchers examined analyzing risk and negative effects of adverse life events on children (Waller 2001, 290). At present, there are two dominant paradigms of resilience (Hsu 2011, 14), both of which have evolved from ecology. One of the dominant definitions of resilience is given by Holling (1973) in his study of behavior of ecological systems, called "ecological resilience". It is defined as:

> "The persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist (Holling 1973, 17)."

It emphasizes existence and absence of systems (Holling 1973, 17). He criticizes the old dominant view that assumed a stable environment where the nature would self-repair when human stressors were removed, and argued that this does not help understanding behavior of a system that is not near equilibrium (Holling 1973). This is simply because ecosystems are dynamic and they respond to external influences continuously on a range of different time scales (Klein et al. 2003, 39). The old view led to the interpretation of resilience as return time after disturbance, which is another dominant definition of resilience (Holling 1996, 330). It emphasizes the speed of recovering from a disturbance to its original state, called "engineering resilience", in which disturbance can be translated into impact. It is defined as:

> "How fast a variable that has been displaced from equilibrium returns to it. Resilience could be estimated by a return time, the amount of time taken for the displacement to decay to some specified fraction of its initial value. (Pimm 1991, 13)"

3.2.2 Social Resilience

Resilience has also become a word to describe the behavior of communities, institutions and economies to external influences in social science (Klein et al. 2003, 39). Resilience to natural disasters, particularly, has been increasingly important and seen in literatures since climate change can increase the potential risk of natural disasters which is no longer reduced only by reducing green-house gas emissions (Arnell et al. 2002). Adger (2000) defines social resilience in relation to the concept of ecological resilience as:

"The ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change (Adger 2000)."

He argues that social and ecological systems are linked, meaning that social groups and institutions are directly dependent on their natural resources (Adger 2000, 350). Social resilience has economic, spatial and social aspects, thus it needs to be analyzed at different scales in an interdisciplinary manner (Adger 2000, 349). It is, however, contested in social sciences whether resilience in ecology can be applied to social systems, which allows assuming that there is no essential difference in behavior and structure ecological and social systems (Adger 2000, 350). Conversely, Dovers and Hanmer (1992, 276) took consideration of the difference between ecosystems and social systems into resilience, which is the human capacity for anticipating and learning. They distinguish between the reactive and proactive resilience of society. Reactive resilience emphasizes strengthening the present system to resist to the change, whereas proactive resilience accepts inevitable change and emphasizes the system to adapt to new conditions, which is close to adaptive capacity discussed below.

3.2.3 Resilience as System Attributes

Over the past thirty years of resilience research efforts increased the recognition of linkage between social and ecological systems, which led to formation of Resilience Alliance, the network-based organization formed with scientists in ecology and ecological economics (Klein et al. 2003, 40). The organization argues the three defining characteristics of resilience of social-ecological systems as:

i) The amount of disturbance a system can absorb and still remain within the same state or domain of attraction
ii) The degree to which the system is capable of self-organization.
iii) The degree to which the system can build and increase the capacity for learning and adaptation (Resilience Alliance 2011).

This became the basis of scientific background for the World Summit on Sustainable Development in Johannesburg in 2002 (Folke et al. 2002) and was also adapted by the UN International Strategy for Disaster Reduction (UNISDR). The definition provided by Resilience Alliance as well as proactive resilience, recent interpretations of resilience include aspect of building or increasing capacity of learning and adaptation. In this context, resilience is often used in conjunction (Carpenter et al. 2001, 765). Klein et al. (2003, 42) also criticize that the concept of resilience is not only making confusion because of its diverse definitions but also is only an umbrella concept which is vague and the broadest meaning, thus, it is difficult to use in practice such as policy and management purposes (i.e. measurement, testing and formalization). Instead, by referring reactive resilience (Dovers and Hanmer 1992, 276), they propose adaptive capacity as umbrella concept and resilience as one factor influencing adaptive capacity, with the two specific system attributes:

i) The amount of disturbance a system can absorb and still remain within the same state or domain of attraction
ii) The degree to which the system is capable of self-organisation.

3.2.4 Similar Concepts to Resilience

To avoid confusion, similar concepts to resilience and their definitions are shown in Table 4 although it is not exhaustive.

Table 4. Similar concepts to resilience

Concept	Definition
Stability	The ability of a system to return to an equilibrium state after a temporary disturbance (Holling 1973, 17).
Adaptive capacity	The ability to plan, to prepare for, to facilitate, and to implement adaptation options (Smit et al. 2003).
Robustness	The maintenance of system performance either when subjected to external, unpredictable perturbations or when there is uncertainty about the values of internal design parameters (Carlson and Doyle, 2002).

3.3 Resilience and its Dimensions to be Analyzed

The speed of restoration of the existing energy supply system (i.e. restoring transmission lines) after the disaster is not the main focus here although it is important in terms of disaster risk reduction. Maintaining energy supply above acceptable level is more important for human survival in the initial phase after the disaster because shortage of energy supply from other locations is inevitable if a large-scaled natural disaster hits as Kamaishi experienced. Therefore, engineering resilience and stability are not appropriate concepts here. Robustness is not appropriate either since a social system is never fully designed and controllable, and the majority of components are self-organizing and uncertainty is high in contrast to designed systems (Andeies et al., 2004, 18). Adaptive capacity is an important aspect to prepare and plan for future natural disasters, but it needs analysis of multiple dimensions of communities and institutions on a range of different scales, which are out of the focus of the analysis in this research. Even though this is the case, social learning and adaptive capacity, which would enhance the ability to cope with future natural disasters, are discussed in Section 4.5.

Resilience definition proposed by Klein et al. (2003), resilience as systems attributes, is consistent to the context of the problem rather than the one including capacity of learning and adaptation (e.g. Resilience Alliance), and it is more practical because it helps setting dimensions to be analyzed. From practical perspective, resilience as umbrella concept (e.g. Holling (1973), Adger (2000) and UNISDR (2009)) is too broad to use for analysis, and adaptive capacity should be seen separately.

Table 5. Resilience as systems attributes and its dimensions to analyze

Attributes	Dimensions to analyze
i) The amount of disturbance a system can absorb and still remain within the same state or domain of attraction.	• Impacts of energy shortage on life • Measures and behavior to manage energy shortage alternatively
ii) The degree to which the system is capable of self-organization.	• Social networks within a community • Cooperation amongst residents to use energy efficiently.

Table 5 shows the systems attributes of resilience and the corresponding dimensions to be analyzed. This thesis discusses how communities coped with energy supply shortage caused by the earthquake and tsunami by managing their limited energy sources or by cooperating within the communities, especially in the first a few days after the disasters. Primarily, the dimensions of the first system attribute, which are impacts of energy supply shortage on individual´s life, and measures and behavior taken to manage the problem, are analyzed. The thesis also discusses the second attribute, of which the dimensions are social networks and cooperation amongst residents to cope with the problem, but it is limited due to the limitations of the semi-structured interviews as discussed in Section 3.3.

There is a remaining problem in use of the above definition because quantitative data regarding the dimensions of the problem (e.g. amount of electricity supply for a particular community from emergency generators, amount of gasoline saved, and number of neighbors whom you can rely on) were difficult to collect in this research since it needs more time. Thus, in this research, only qualitative data we collected and they were the dimensions in Table 5 were analyzed by performing social survey and systems analysis.

4. Results and Discussion

4.1 Results from Literature Survey (Damage situation in Kamaishi City)

The three severely affected districts (Unosumai-cho, Tenjin-cho, Toni-cho), circled with blue line in Figure 9, were selected for semi-structured interview with 97 residents. The rational of choosing those areas are; the level of damage and geographic features are different amongst those areas, and it was assumed that these as well as other social factors might affect the impacts of energy supply shortage.

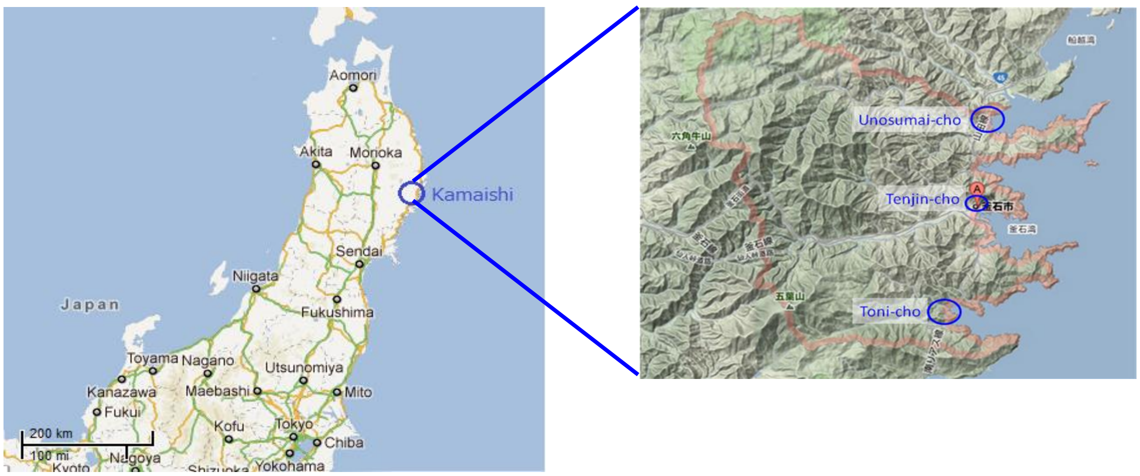


Figure 9. Three areas where semi-structured interviews were conducted (Source: Google Map)

As Figure 9 shows, the entire coastal areas of Kamaishi are shaped with narrow inlets and steep terrains, which tend to increase the amplitude of tsunami. Unosumai-cho in Unosumai District is located in the north in Kamaishi, right next to another municipality of Otsuchi, where there had the most severe damage in Kamaishi (Table 6). Tenjin-cho is one of the areas in Kamaishi District, which is the downtown of Kamaishi, with many residential and commercial buildings. The district also had the second largest damage after Unosumai District (Table 6). Toni-cho in Toni District is a fishing village located in the south in Kamaishi. Many private residences were built at high point as the topography of the area becomes steep right near the port. The level of damage including deaths and missing persons is relatively smaller than other districts (Table 6).

Table 6. Damage situation in Kamaishi (November, 2011)

(Adopted from Kamaishi City.Disaster Countermeasure Office of Kamaishi City)

District	# of Destroyed houses[10]	% of destroyed houses	# of Deaths or missing persons	% of deaths or missing people
Unosumai District	1,515	51.3	583	62.6
Kamaishi District	1,005	34.0	229	24.6
Toni District	254	8.6	21	2.3
Other Districts	180	6.1	98	10.5
Total in Kamaishi	2,954	100.0	931	100.0

4.2 Results from the Interviews

4.2.1 Residents' Answers

During the interviews, the residents including those who stay in emergency housing units (houses built for people who lost their homes by the tsunami) were randomly visited and interviewed one by one. The number of interviewees is 28 in Unosumai-cho (of which 14 in emergency housing), 34 in Tenjin-cho (of all in emergency housing) and 35 in Toni-cho (of which 18 persons in emergency housing). In many cases, residents preferred to stay at the emergency housing close to their home location simply because of staying close to neighbors within the same community.

In each interview, the following three core questions were asked:

1) If you do not mind, what is your age range?
2) When the supply of electricity, oil and gas were stopped because of the disaster, what were the most significant effects on your life? For example, no communication, no lights, etc…
3) Where did you stay right after the disaster?

Further questions were asked depending on the context of responses. For instance, in case of receiving more general answers (i.e "everything was lacking"), further specific questions were asked to get more detailed answers (i.e. "what were particularly necessary when you did not have such as electricity and heating oil?"). All the raw data are shown in Appendix A.

[10] Number of destroyed houses does not count houses partially destroyed.

Quantitative data shown in the following graphs are based on the interview data with 97 residents in the three different areas in Kamaishi, which help us understanding tendency of energy services in need and place to evacuate, and differences between those three areas.

4.2.1.1 Demographical Figures

Of all the interviewees, 66 were female whereas 31 were male. In terms of age group, 68% of all the interviewees were over 60 years old (one interviewee did not answer the question about age group) (Figure 10). The reasons why the majority of interviewees were female and elder people can be twofold: Firstly, most of the interviews were conducted during daytime and weekdays when it is very likely that male and younger generation were working or studying at school. Secondly, the demography of entire Kamaishi is rather old (Kamaishi City, 2009).

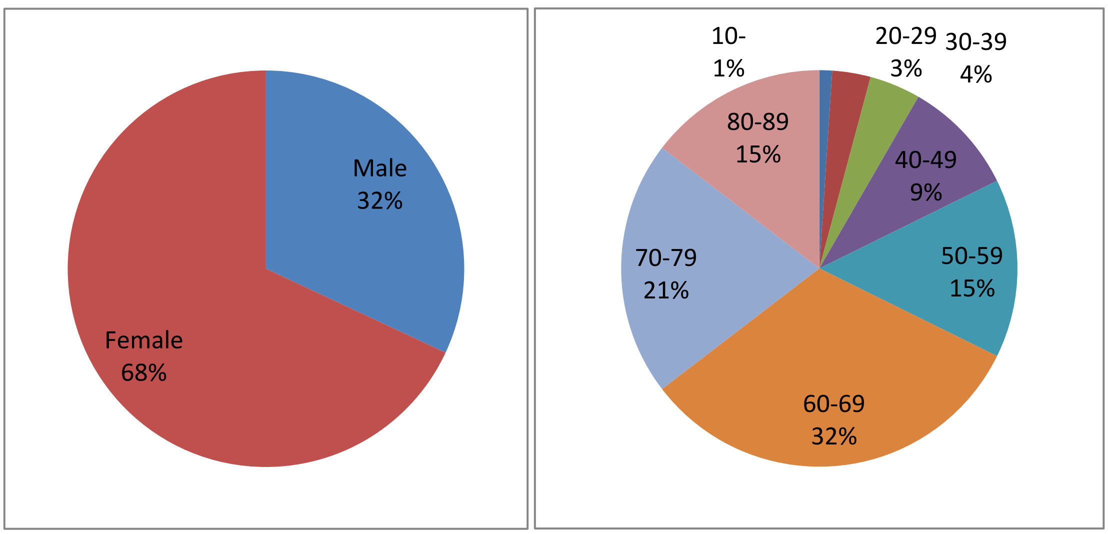


Figure 10. Gender (left) and age group (right) distribution of 97 interviews

4.2.1.2 Energy Services in Need

Figure 11, 12 and 13 are the graphs based on the quantified data originally collected by performing semi-structured interview with 97 residents. For the question 2), all the responses were coded in terms of energy services in need, with the following criterion. The coded data were categorized into 8 groups[11] (see Appendix B).

[11] 8 groups are heating, communication/information, water, cooking lighting, mobility, bath and not particular. There are sub categories under water and mobility, for which several persons mentioned the same energy services. Sub categories are toilet and others (water) and buying foods, hospitals and others (mobility).

1) Suffered without energy service and no alternative. If there was an alternative way that enables providing a similar energy service (i.e. oil stove heating instead of electricity heating), no count.
2) Candle as alternative lighting is counted because its brightness is too little. But lantern is not counted.
3) Electric heating and stove heating are counted together as 'heating'.
4) Cooking with electricity and cooking with gas are counted together as 'cooking'.
5) Use of wood for heating fire and cooking is counted.
6) 'Saving electricity´ or other fuels is not counted.

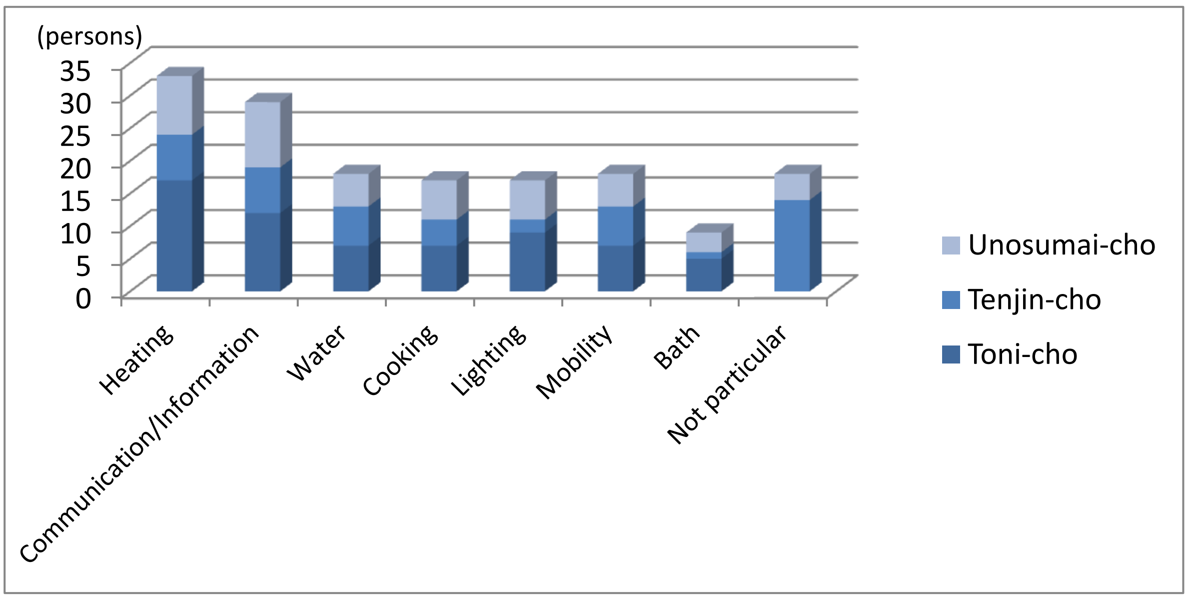


Figure 11. Energy service needed in the three areas in Kamaishi

Figure 11 shows energy services, which the interviewees needed but could not use right after the disaster due to energy supply shortage[12].

The graph shows that 'Heating' (34% of the total interviewees) and 'Communication/Information' (30%) were particularly necessary, but were not available because of blackout and fuels were in shortage. When the disaster occurred, it was still very cold and was snowing in Kamaishi. The cold weather made it difficult for elder residents to stand without heating. Some who did not have either an electric heating facility or a heating stove suffered from the severe coldness, but others who had a heating stove with

[12] The sum of the total number of persons for each type of energy service is over the total number of interviewees.

sufficient heating oil could manage it. ‘Communication/Information’ means there was no or little ways to communicate with others by telephone, mobile phone and e-mail, and to access information by TV, radio and the internet. Some said they needed to communicate with their family or relatives to confirm their safety, others said they had no idea of what was happening because of no information of the disaster. Telephone and mobile communication were unavailable not only because of electricity outage but also damage on communication facilities (e.g. transmission lines) (Softbank ibid). 19% of the total interviewees raised ‘Water’, of which the 72% said that they were in trouble without flushing toilet that needs relatively a large amount of water compared to cooking or drinking. The rest mentioned drinking water. 18% interviewees answered ‘Cooking’, especially those who used electric cooking system had no alternative way of heating water and foods. On the other hand, some households could use LPG for these purposes. 18% chose lighting and they used candles instead, of which only 11% chose this in Tenjin-cho. Interestingly, some residents in Toni-cho who are fishermen, used lights in their squid fishing boat that worked quite well as alternative. 19% chose ‘Mobility’ as it was vital for some residents to bring their family, who were injured by the tsunami, to a hospital. Needless to say, public transportation systems were stopped as well. There were also residents who needed to find missing family members, and needed to buy foods as they were very limited before supplied. It is important to mention that Toni-cho was isolated for a certain period since the disaster because the road to other areas was blocked by a large amount of wreckage of buildings until these were cleaned up. This could be a reason why relief supplies were relatively late to reach Toni-cho compared with other areas. ‘Bathing’ (9%) is a daily-custom for Japanese people, but they could not bathe because water could not be heated. 19% chose ‘Not particular’, of which 74% are interviewees in Tenjin-cho and nobody in Toni-cho.

4.2.1.3 Place to Evacuate in the First Three Days after the Disaster

The responses for the question 3) were coded and categorized into the 6 groups for quantification. Figure 12 shows where the residents evacuated to during the first 3 days after the 11th March, 2011. The intension of this section is to see correlations between the areas where the interviews were conducted[13] and place to evacuate, and eventually to compare with needed energy services. As it took a few days until people affected get relief supplies such as foods, water and fuels, it is considered that the first 3 days are the most vital for evacuees to survive with self-reliance in this paper. Some interviewees answered that they stayed over one place (i.e. 1 day at home, 2 days at shelter). A place they stayed for a longer period is counted for such a case. But in case an answer is not clear how many days they stayed

[13] It means places where the interviewees lived when the disasters occurred.

one place, the first place they evacuated is counted. One interviewee did not answer to the question 3); the sum of the answers is 96.

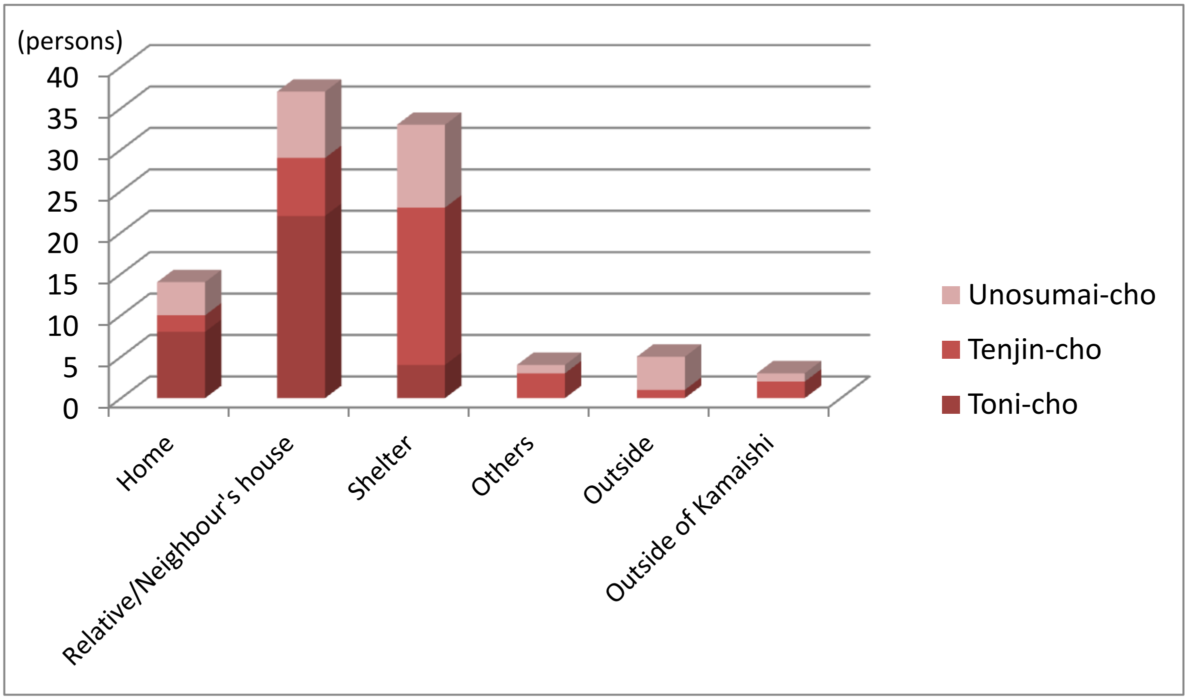


Figure 12. Place to evacuate right after the disaster (first 3 days)

Figure 12 shows the clear difference amongst the three areas. While 24% of the interviewees in Toni-cho stayed at their home and 65% stayed in their relative/neighbor's home (mostly, in Toni-cho), 56% in Tenjin-cho and 34% in Unosumai-cho stayed in shelter[14] the downtown or more inland areas in Kamaishi. This difference implies the next two points. Firstly, the social network within community could be relatively stronger in Toni-cho than other two areas. Many residents had their relatives lived in the same area, and they knew well and could help each other. Secondly, in Toni-cho, although many houses near the port were destroyed, those located at high point were safe while many buildings were destroyed on the flat area and close to the sea in the downtown and Unosumai-cho as Table 6 shows. Therefore, it might be difficult for evacuees in Tenjin-cho and Unosumai-cho to find a home nearby to stay although they might have relatives in the same area, thus public buildings played important roles. It is also important to note that 4 % in Unosumai-cho stayed outside (in a mountain) for the first three days.

[14] Shelter means a public or private building in which many evacuees stay together. For instance, school, hospital and elderly care center.

4.2.1.4 Energy Services Needed Depending on Place

Figure 13 shows energy services needed depending on place where the residents evacuated. It is obvious that there are more counts for 'Relative/Neighbor's home' and 'Shelter' as many of the interviewees stayed there. 34% of the interviewees who stayed in their 'Relative/Neighbor's home' chose 'Mobility'. One possible reason is that they might need to drive to buy foods as they might share limited foods with many persons. But it does not seem that there is a strong correlation between staying in 'Relative/Neighbor's home' and needing mobility because 56% of the interviewees who raised 'Mobility', needed to drive to find missing people or for other reasons rather than buying foods. What is important in this graph is 42% of those who stayed in shelter chose 'Not particular' and many of them were interviewees in Tenjin-cho. This result implies that , compared to other places to evacuate, there is tendency that those who were in shelter had fewer troubles in terms of energy service as some of them answered there were a power generator and oil heating stoves. This can be because it was known that there were people evacuated to shelter and it was more efficient than distributing relief supplies by visiting private residence one by one. Some answers from those who stayed at home also support this. One said 'we at home were not supplied with foods and lights, but shelters were supplied.' Another person said 'I stayed with 10 persons at my home and did not go to a shelter. I have never had such a poor experience.'

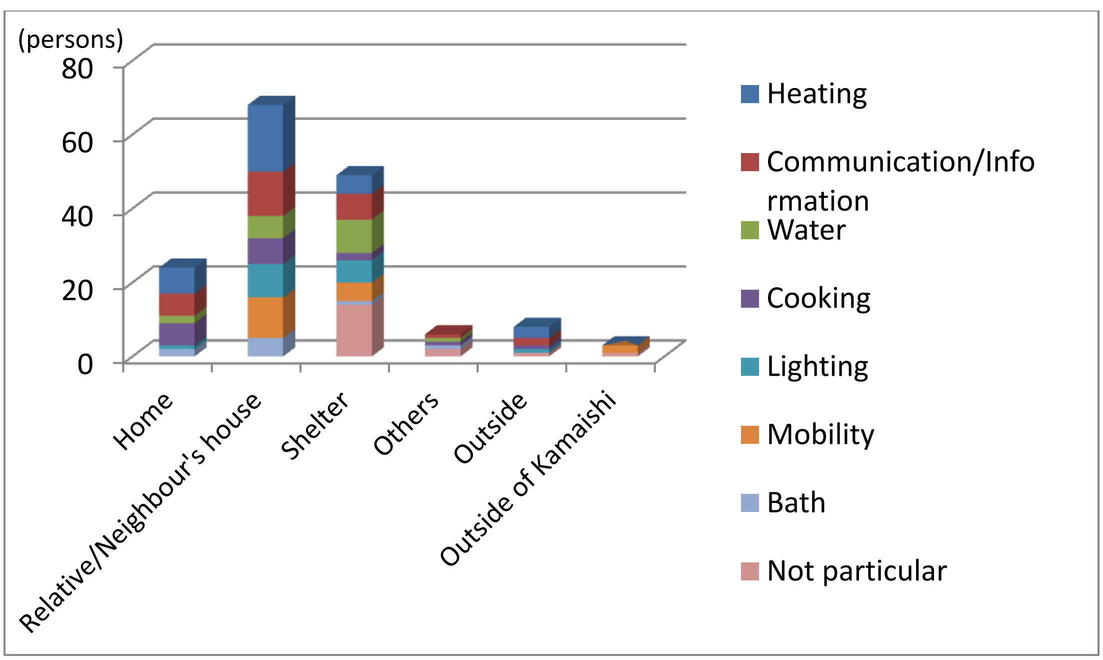


Figure 13. Place to evacuate and energy service needed

4.2.2 Steel Memorial Hospital's and Kamaishi Works of Nippon Steel Corporation's Answers

There were not significant impacts on medical services and patients in Steel Memorial Hospital. Although electricity was not supplied from the regional grid system, the electricity generator for emergency worked and the enough light oil for electricity generation was remained. Some light oil was also supplied from Kamaishi Works of Nippon Steel Corporation as the hospital belongs to the group of the company. Heating also functioned although the fuel use was a little saved. According to the interview with the hospital, there were not significant impacts of energy supply shortage on medical services in other hospitals that were not directly affected by the tsunami in Kamaishi, either.

The crucial problem in Kamaishi Works of Nippon Steel Corporation was in protecting their facilities in the situation of blackout. Kamaishi Works had the coal-thermal plant (MW) running as Independent Power Producer (IPP), which produced and sold electricity to Tohoku Electricity Corporation through the regional grid system. When the blackout occurred, the turbine of the plant needed to be kept rotating with alternative electricity supply since its temperature was high. Otherwise, damage for the turbine would be quite huge, which means the shape of the turbine would be changed because of its temperature. Thus, electricity was supplied to keep rotating the turbine by the electricity generator for 3 days, until the temperature decreases enough. Since the amount of light oil for the generator was for a half day in the fuel tank, which was in maximum, additional fuel was necessary to be supplied from the tanks of the tracks of Nippon Steel Logistics Corporation in the same area every half day. Kamaishi Works had another electricity generator (6MW), but it was stopped running because: 1. all the electricity from it could not be used; 2. fuel (heavy oil) was limited to only for a few days; and 3. it was more appropriate to use the fuel for other purposes in the emergence situation. There were other problems due to blackout such as water supply stop, and limited communication and information. But, company phones had batteries and they communicated with outside the organization by using a satellite phone. One problem was it took time to confirm the safety of the all the employees because electric files of employees' list were in the computer, which could not be turned on.

4.3 Systems Analysis of the Impacts of the Energy Supply Shortage Based on the Information Gathered from Literature Survey and the Interviews

In this section, systems thinking approach and causal loop diagramming methodology are applied first to identify and analyze the causes and effects of the energy supply shortage in Kamaishi and then to come up with alternative measures to respond, recover from and reduce the shortage in energy supply. Here the specific case is focused, but the analysis is conducted in a generalized manner.

4.3.1 Causes and Impacts of Energy Supply Shortage

Causal loop diagram given by Figure 14 shows the key components of the energy supply system in Kamishi. Causes for the energy supply shortage and the negative impacts of this shortage on the individuals' life are shown with this CLD.

Some of the interrelations between the components of the system are simplified for generalization and understanding easily. Words written in red are original causalities of energy supply shortage (i.e. magnitude of earthquake), those in blue with underline are energy services in need (i.e. heating, lighting), and those in a rectangular means 'stock' (i.e. heating oil available, water available). In the following descriptions, the components are written in bold.

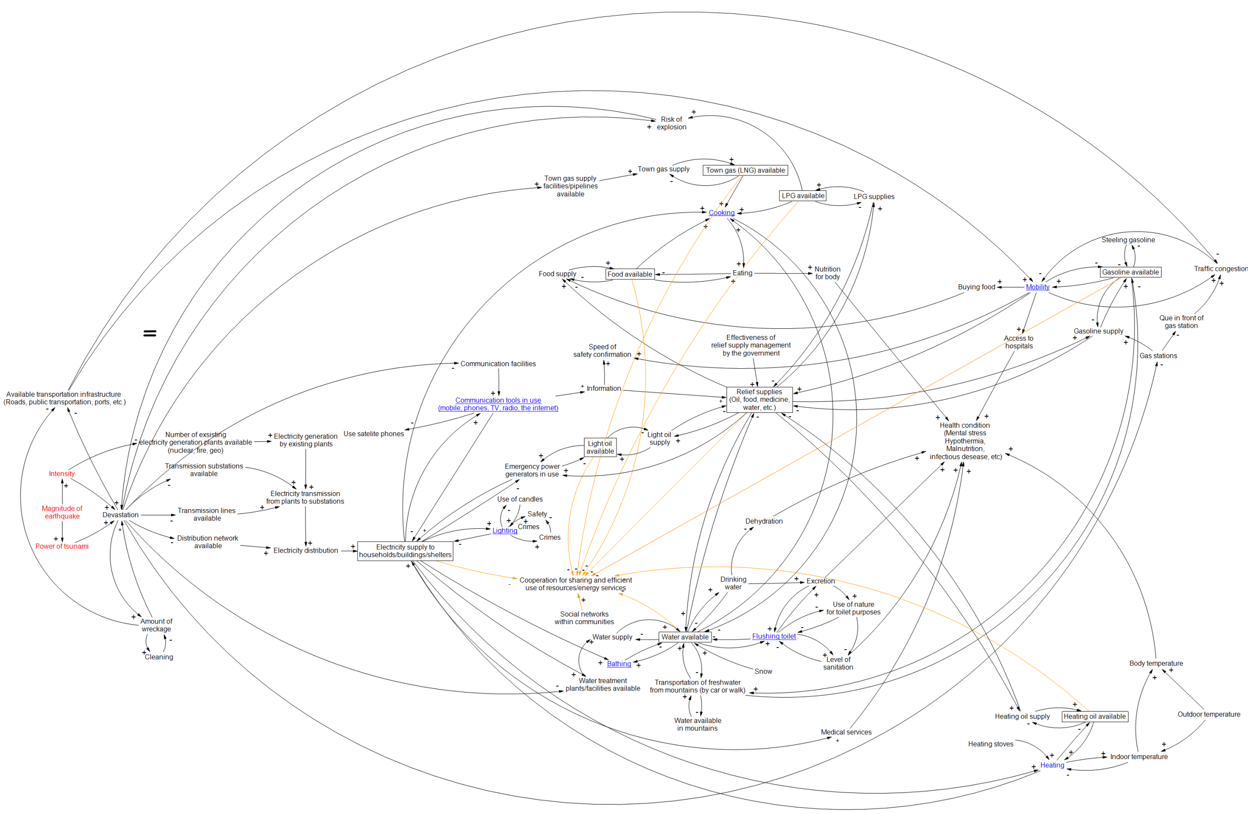


Figure 14. CLD of causalities, impacts and feedbacks of energy supply shortage in Kamaishi (See Appendix D for the expanded version)

Generally, the higher the magnitude of the earthquake is, the higher the intensity of the earthquake and the power of tsunami are. There are several other factors affecting the intensity of the earthquake and the power of tsunami (i.e. location of earthquake origin and topography of coastal areas etc.), but these factors are not shown in the CLD. Both the intensity of earthquake and the power of tsunami determine the level of devastation. The severer the devastation becomes, the larger the amount of wreckage is produced, and together which destroys the transportation infrastructure (i.e. roads, rails, ports etc.)

Electricity supply - The number of existing electricity generation plants available reduces with the intensity of the earthquake, hence, the less electricity generation from the existing plants. Once the intensity of earthquake exceeds a certain level, the electricity generation plants automatically shut off due to safety systems. This in fact what had happened in Tohoku Region, where the electricity is produced and transmitted to Kamaishi. More devastation leads to less number of available transmission substations, transmission lines (including towers) and distribution networks. Thus, electricity transmission from plants to substations and electricity distribution decrease. In the coastal areas in Kamaishi, tsunami and wreckage of buildings severely damaged distribution networks such as power lines and utility poles. Needless to say, with no electricity produced and distributed to these areas, electricity supply to household buildings/shelters becomes zero (electricity outage). Areas where distribution networks were not destroyed received their electricity once the transmission substations and lines were restored.

When electricity is not supplied through the distribution network, it can still be generated by emergency power generators mostly stationed in shelters and hospitals. Fuel needed to run these generators, is light oil, and once there is shortage of it, it comes from other locations as a relief supply (see below for further information about other relief supplies). Lack of electricity creates a range of impacts on society varying from communication to water availability, to heating, etc.

Water - Electricity is necessary for water supply system including the water treatment plants, which were severely damaged by the devastation in Kamaishi. The main problem caused by the water supply shortage is the reduced health conditions due to decreased levels of sanitation and dehydration.

Interviewees highlighted four areas of water usage; drinking, cooking, bathing and flushing toilets. Flushing toilets is one of vital problems here as relatively a large amount of water is required and lack of water generates sanitary and in turn health issues. Use of the nature for toilet purposes does not require water, where as it decreases the level of sanitation. People can also suffer from dehydration in case of not drinking enough water. Transportation of freshwater from neighboring mountains and melting of accessible snow were mentioned as two alternative ways of increasing the water available.

Lighting - Lack of lighting due to electricity outage generates some safety issues including increased level of crime. Actions can be taken during dark time are very limited in this situation. Use of candles as an alternative way of lighting was mentioned by the majority of the interviewees.

Communication - Because of communication facilities (e.g. electric wave towers, transmission lines) destroyed by the devastation and the lack of electricity supply, people cannot not use communication tools (e.g. phone call, sending e-mails). This prevents them to access to vital information (i.e. situation, information of relief supplies) and to confirm the safety of family members and the relatives.

It is also difficult for them to inform outside of the city how the situation is and what types of assist is needed (relief supplies). Satellite phones are used in such a case, but number of satellite phones is quite limited in general. Use of satellite phones allows the user to have access to information.

Heating - Lack of proper heating is a vital problem especially when the outdoor temperature decreases to below 0 degree. Houses with only electric heating facilities suffer dramatically when there is no electricity supply. Those who are forced to stay outside struggle with the coldness as well. Risk of hypothermia, especially for elderly people and young children, may increase if their body temperature becomes low because they stay in the cold environment for many hours. Oil heating stoves can be used as alternative as far as heating oil is remained. Additional heating oil together with other relief supplies come from other locations.

Cooking – Lack of cooking becomes a serious problem in households with only electric cooking systems. Even those houses using town gas (LNG) have the same problem, since the devastation affects the town gas supply facilities including the pipelines. But, those with LPG (Liquefied Petroleum Gas) do not have such problem. If a local LPG supplier owns electricity generator and LPG stocks, they may supply LPG for those who need. In addition to the means for cooking, availability of water and food are the two other factors affecting cooking. Available food is limited in the beginning stage after disaster occurs. In such a situation, those who do not eat sufficiently may lack nutrition. It is also important to mention that LPG has risk of explosion when severe natural disaster hits and gas is discharged, which can cause fire and further devastation.

Mobility – When gasoline is in shortage mainly because the gas stations are out of service due to the devastation, lack of mobility becomes a crucial problem. Since available transport infrastructure is damaged or blocked due to devastation by tsunami and wreckage of buildings, more traffic congestion is enhanced. Public transportation does not function, either. Long queues in front of the gas stations that are functioning created traffic congestion. Traffic congestion decreases mobility, and it eventually would affect delivering relief supplies. Cases of stealing gasoline increase when available gasoline is limited. Three major negative impacts of the lack of mobility are defined as having problems with access to hospitals, to food and the speed of safety confirmation of the family members.

Relief supplies – Supplies needed to maintain the daily life such as food, drinking water, emergency electricity generators, batteries, light oil, heating oil and LPG constitute the relief supplies. They are mostly brought from outside of Kamaishi City, all over Japan which is not affected. There are several factors affecting the speed of the transportation and the amount of the relief supplies. First of all, fuel supply chains themselves are devastated (e.g. local suppliers including staffs, tankers, and oil and gas terminals, oil refineries, oil factories). Problems with the transportation infrastructure and lack of gasoline affect the level of mobility in a negative way. Communication plays a crucial role to pass the information concerning which and how much of relief supplies are needed. The effectiveness of governmental (national, prefectural and municipal) management of relief supplies affects the speed and accuracy of transporting. The complication in the national government may delay the decision of the transportation.

Collaboration for sharing resources and energy services – Reduced available resources such as oil products, gas and water and energy services lead to more cooperation within communities to share them or to use efficiently. It is important to note that the degree of cooperation would be affected by the level of social networks within communities, which means how much residents know and establish good relationship to support each other.

4.3.2 Potential Alternative Measures in Response, Recovery and Risk Reduction Phase

Figure 15 is the CLD with some potential alternative measures to tackle the energy supply shortage problem. Response stage is the most important here in terms of resilience building because its aim is to increase ability of society to survive or persist against natural disasters so that human needs (services or actions that need energy supply) are met. Response is defined as the period that immediately follows the occurrence of the disaster. This means that there are alternative energy supplies, which support individual's life or other social functions (i.e. medical services, communication) with self-reliance (until enough assists from other locations arrive, which takes a few days in general) although natural disasters stop or disturb the existing energy supply system functioning. Therefore, it would be safe to say that the more options of energy supply, the less negative impacts of energy supply shortage caused by natural disaster, and the more resilience society is.

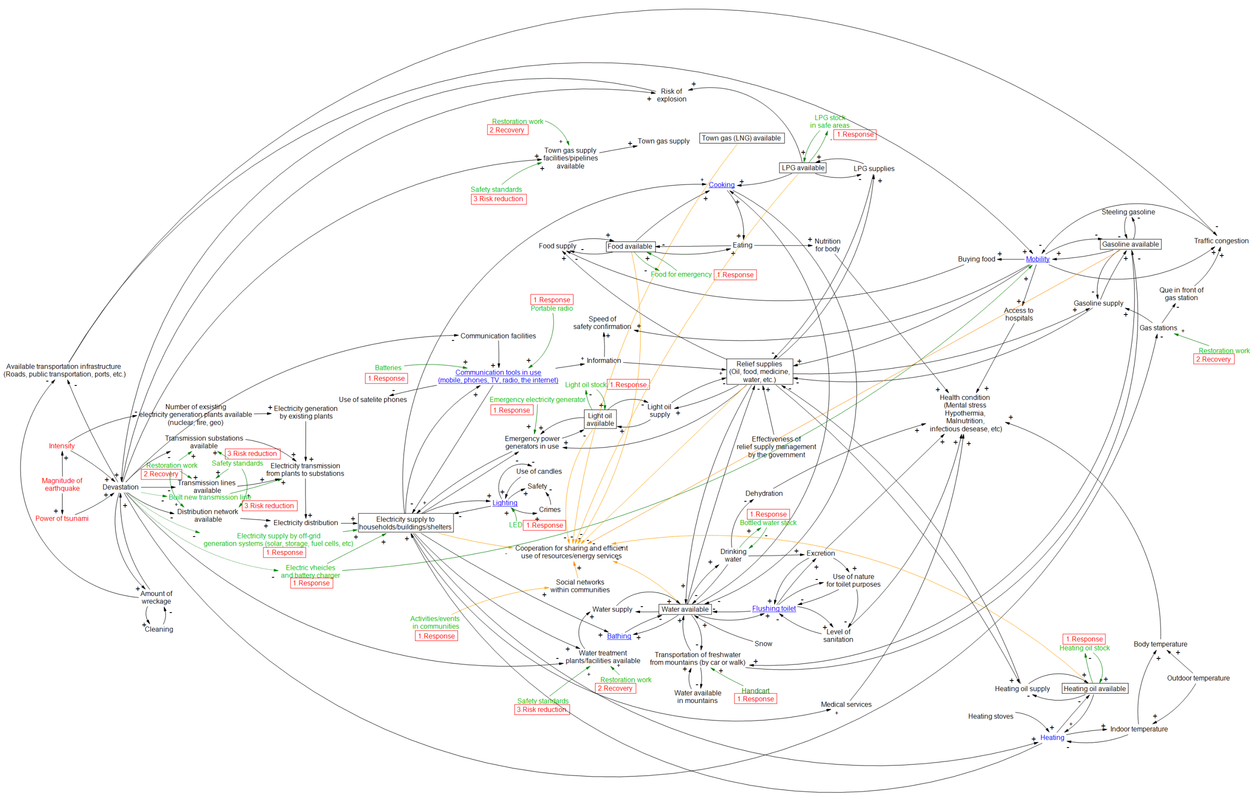


Figure 15. CLD with potential alternative measures for risk reduction (See Appendix D for the expanded version)

4.3.2.1 Response Phase

Electricity – Electricity supply is the most vital problems and needs improvement. As Figure 15 shows, when electricity distribution lines are destroyed, although other parts of electricity supply network are restored, there is no electricity supply to households. Thus, ideally, the effective measure is installing alternative electricity supply system which can operate when electricity supply from the existing grid is disturbed. In other words, decentralized local electricity supply system discussed below can be a useful concept as comprehensive solution. The concept as well as its advantages and disadvantages are discussed, and potential technical measures are proposed below.

(1) Concept: Decentralized Local Electricity Supply System

As the most common technical term, 'distributed generation (DG)' is used (Karger and Hennings 2007, 583), which refers to "generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages." The DG technologies include engines, small (and micro) turbines, fuel cells, and photovoltaic systems in general (IEA 2002, 19). A shift towards DG has been gaining more policy attention in some industrialized countries due to the five factors: liberalization of the electricity market, technology development of DG, constraints on the construction of new transmission lines, increased customer demand for more reliable electricity and especially climate change (IEA 2002, 20). But definitions of the word vary depending on literature (Ackermann et al. 2001) and there is no consensus on a precise definition (Pepermans et al. 2005). There are also similar but different concepts (i.e. dispersed generation, distributed power, decentralized power) (IEA 2002, 20). Ackermann et al. (2001) uses "decentralized electricity generation", which means "an electric power source connected directly to the distribution network or on the customer side of the meter." The term 'distributed utility' is used in the US, which includes local storage and demand side measures as well as local generation facilities (Feinstein et al. 1997). In order to discuss concrete measures to tackle energy supply shortage when natural disaster occurs, it is the must to define the term in the context of the problem.

As a lesson from the Great East Japan Earthquake, Onoue et al. (2012, 4) propose "decentralized local electricity supply system" that can operate independently of the existing central electricity supply system. Central electricity supply system here means the electricity supply system which is hierarchically structured electricity supply network (from plants, transmission lines to distribution lines) and is operated by monopoly regional electric power corporations (e.g. TOHOKU-EPCO). It does not mean that the decentralized system is completely separated from the centralized system, but it is networked and can still operate with local electricity sources when the centralized system does not function. Thus, communities affected by natural disaster can access electricity supplied from the local electricity sources and impacts of electricity outage of the centralized electricity supply system on individual's life can be mitigated. But what Onoue et al. (2012) propose more specifically is utilizing fuel cells as "fuel cell-based decentralized energy system" rather than renewable energy fluctuating with weather conditions. In this thesis, other technical options as well as fuel cells should be considered for the purpose of resilience building although their proposal is useful at conceptual level. Here the term, decentralized electricity supply system, is used because the term is more comprehensive than DG. It includes any facilities that supply electricity including storage and grids as well as generation, while DG or decentralized generation seem to limit measures for electricity supply. By taking consideration of those concepts above, 'decentralized local electricity supply system' is redefined as:

> "Electric power supply system with local power sources that are directly connected to distribution network or serve customer on-site. The system can operate independently of the centralized electricity supply system and the decentralized system feed into the centralized electricity supply system to some degree. Technologies for power source included in the decentralized system are emergency electricity generators (traditional internal combustion engines), electricity storage batteries including electric vehicles, renewable energy (solar PV and wind) and fuel cells. Demand-side measures are included as well."

However, it must be noted that there are more issues that need to be discussed to define the concept more precisely, which is important in implementation. They are, for instance, the purpose, the location, the power delivery area, the technology, the environmental impact, the mode of operation, the ownership and the penetration of distributed generation (Ackermann et al. 2001, 196). Advantages and disadvantages of decentralized local electricity supply system are different and have different effects depending on technical, economic and social conditions (i.e. active governmental involvement in climate change, energy mix, electricity market, etc.). Thus, they need to be considered with specific scenarios rather than simply considering the decentralized local electricity supply system at conceptual level (Karger and Hennings 2007, 585).

From the next, some technical measures of decentralized local electricity supply system are discussed to mitigate impacts of electricity outage of centralized electricity supply system based on the CLD (Figure 15).

(2) Potential Technical Measures of Decentralized Local Electricity Supply System

A. Emergency Electricity Generators (Traditional Internal Combustion Engines)

In short term, the realistic measure is to set up emergency electricity generators (or traditional internal combustion engines or diesel engines) in public buildings such as municipal buildings, hospitals, schools and community buildings which play vital roles for disaster risk management and human survival in case of natural disaster. Electricity outage also affects other energy supplies such as LPG. LPG cannot be filled into cylinders without electricity. Thus, local LPG suppliers should own a generator so that LPG can be supplied quickly to affected people (i.e. one of the LPG suppliers in Kamaishi owned). Increasing stock of fuel (heavy oil and light oil) enables electricity generation for longer hours which mitigate impacts of electricity outage before sufficient relief supplies arrive. For improvement, it is also important to consider locations where a generator is equipped. Some areas could be isolated right after natural disaster and many elder populations are difficult to move other location, hence, a generator needs to be equipped in such areas (i.e. Toni-cho).

But it is important to note some disadvantages of emergency electricity generators. They generally operate from hours or one or two days depending on stock of fuel. Thus, as noted above, they cannot generate electricity when fuel stock runs out or fuel has to be saved as some experienced in Kamaishi. Secondly, they are not mechanically tolerant to be used for long hours and they discharge a large amount of air pollutants and make noise. Thirdly, they are used for only emergency, which means they sometimes do not operate reliably (Yokoyama 2011). While emergency generators have been introduced already and may be easy to choose as a measure to tackle the problem, in mid- to long-term, other measures should be introduced not only they could be more reliable than emergency electricity generators but also there are other benefits socially, environmentally and economically.

B. Electricity Storage Batteries and Electric Vehicles

In mid-term to long-term, the key means is electricity storage battery. The cost for large scale electricity storage batteries is still high, but storage capacity of small-scaled batteries has been increasing and the cost has been decreasing because of technology development (i.e. LG's Lithium Ion (Li) Batteries costs USD350-450/kWh in 2011) (Murakami and Fukui 2011). Electric vehicles (EVs) as means of electricity storage should be considered as well. For instance, Leaf released by Nissan Motors is equipped with 24kWh Li-ion battery that can supply to a household for about 2 days (Hata 2011). Average household electricity consumption in Japan is approximately 10kWh/day (FEPC ibid). Although the storage capacity is lower than EV, plug-in hybrid electric vehicles (PHEVs) (Shinoda et al. 2011) are also useful for the same purpose. EVs and PHEVs also can contribute to mobility improvement in case gasoline supply is limited. It must be noted that batteries are not tolerant for water and has danger of releasing a large amount of electricity (Onoue et al. 2012, 5). Thus, from the viewpoint of disaster risk management, they should be located at high point or far enough from the coast where tsunami cannot reach.

C. Fuel Cells

The fuel cells generate electric power and provide heat from chemical energy through electrochemical processes, in which hydrogen and oxygen are combined. Thus, they can be used for both electricity supply and heating. A variety of hydrogen-rich fuels can be used for fuel cells such as natural gas, gasoline and biogas. There are several advantages of fuel cells. Since combustion is not involved, GHG emissions from fuel cells operation are very little. Low emission of air pollutants, small noise, and high efficiency are also their advantages (Farooque and Maru 2001). There are some types of fuel cells such as polymer electrolyte fuel cells (PEFC) and Solid-oxide fuel cells (SODC) (Onoue et al. 2012).

D. Solar Photovoltaic (PV) and Wind Power

Solar PV absorbs solar energy from sunlight, and light photons from solar energy flow electrons, which convert it to electricity. Especially, standalone PV can be useful in emergency response if distribution network is destroyed because it directly output DC electric power to DC load (El-Khattam and Salama 2004, 123). They can be also applied to street or residential lighting and communication use. Wind power is generated when wind rotate blades of a wind turbine, which in turn rotate its attached shaft and operate a pump that generate electricity (El-Khattam and Salama 2004, 123). But the major disadvantage of solar PV and wind power is that electric power generated fluctuates with weather conditions. Besides, unlike EU which has advantage of electricity supply network through the continuous borders of countries, Japan cannot sell surplus electricity from solar or wind and purchase electricity from neighboring countries as it is an island country (Onoue et al. 2012, 3). Therefore, in order to increase utilization of solar PV and wind, more efforts in research and development are needed for large scale storage technologies. But standalone solar PV with batteries are already available, hence, it can be used as emergency electricity source (El-Khattam and Salama 2004, 123).

Gas – LPG in cylinders are useful in the context of disaster risk management because they are not connected to pipeline network such as town gas, and easy to transport. According to the interviews with the residents, those who had LPG could use it for cooking and boiling water in the event. If local LPG suppliers have enough stock and electricity source, they can fill LPG into cylinders. But it is important to note that there is risk of explosion if LPG is discharged from a cylinder, but the risk can be lowered by safety measure (Japan. ANRE 2011a).

Oil Products – Heating oil can be stored for emergency at community or individual level.

Water and Food – In case of water stopped, it is also important and easy to have stock of drinking water and food. Since it is limited, identifying freshwater source outside and preparation for transportation method at community level should be considered in advance.

Communication – Mobile telecommunication companies such as Softbank Mobile and KDDI already have measures to tackle electricity outage. Emergency batteries and electricity generators are set with base stations. Fuel tank for electricity generation can be expanded as well as fuel supply chain to be strengthened (Softbank Mobile, AU). Those companies also address increasing transmission lines (so that transmission works even though one line is shut off) and strengthening safety standard of communication facilities (KDDI ibid). There are some potential measures that individuals can take. Portable radio with batteries is a useful and affordable communication tool when electricity outage and troubles with communication facilities occur. Mobile phones with TV and radio function are also useful to access information broadcasted.

Lighting – Use of LED lights instead of candles enables brighter and safer lighting. Standalone PV with a storage battery is also convenient.

Mobility – Handcart is an affordable and convenient tool to transport large amounts of freshwater without driving a car. It is possible to have heating oil and LPG in stock, although it is important to note that LPG has relatively higher risk of explosion if severe devastation occurs.

Demand Side Measures – Those measures above are mainly supply side measures, but impacts of energy supply shortage also can be mitigated by using energy sources or energy services more effectively. Needless to say, saving energy source till enough relief supplies arrive is important. Strong social networks within a community, for instance, are quite important in the sense that evacuees can help each other and have access to limited amount of resources or energy services (i.e. heating and lighting) in a more effective way. It is practical to deliver relief supplies to shelters, where many evacuees stay together as compared to individual private residences. Therefore, in advance, individuals should recognize where relief supplies are delivered in case of disasters.

Activities and Events within Communities – Stronger social networks within communities are important to enhance their cooperation and support when natural disaster occurs. There are many and different ways to enhance social networks. In general, social activities and events such as social learning of risk disaster management, public meeting, etc can enhance social networks.

4.3.2.2 Recovery Phase

Recovery is defined as phase when the immediate needs of the population are met, when all medical help has arrived and people have settled from the hustle. Restoration work for facilities (i.e. electricity transmission substations and line, distribution networks, water treatment plant, town gas pipelines/facilities and gas stations) needs to be conducted as quickly as possible to recover energy supply systems. From the experience of the Great East Japan Earthquake, it can be said that some technical measures discussed in response phase also enhance of the speed of transporting relief supplies because it is affected by communication and mobility as shown in the causal-loop diagram in Figure 15. At local level, two factors are important for relief supplies delivery: diversity (age, gender, geographical feature, available resources, etc.) and equity even in the same city.

4.3.2.3 Risk Reduction Phase

This is the phase when the population has returned to pre-disaster standards of living. But, they recognize the need for certain measures, which may be needed to reduce the extent or impact of damage during the next similar disaster. Strengthening safety standards of facilities (i.e. transmission substations and lines, distribution networks, town gas facilities/plants and water treatment plants/facilities) and building new transmission lines additionally are potential measure to reduce risk of future disasters. Planning and implementing al the technical measures to supply energy alternatively or mitigate impacts in response phase, which were discussed above, are conducted in this phase. Besides, stakeholders (e.g. municipal officers and residents) participation for the aim of leaning possible impacts of energy supply shortage and solutions by using systems thinking and the planning of risk mitigation measures are recommended. The outcome of such a participatory process is resilience enhancement; hence, negative impacts of natural disaster could be mitigated.

4.4 Theoretical Discussion

Based on the previous discussions, findings at theoretical level in terms of resilience theory and causal loop diagramming are discussed below.

4.4.1 Systems Analysis for Resilience Building

In this research, resilience as system attributes proposed by Klein et al. (2003) was applied to the analysis of impacts of energy supply shortage caused by the disaster. The dimensions corresponding to the system attributes are defined. The collected qualitative data were analyzed in terms of those dimensions by performing social survey and developing the CLDs. Systems analysis was employed to understand the causes and impacts of energy supply shortage. In this research, systems analysis was not an approach to judge whether the system was resilient or not because there was no criterion of the dimensions, but it helped identifying factors that could enhance resilience in terms of energy supply. This is because a whole-system view in systems analysis enables us to see which and how balancing loops working to restore the system when there is an external shock (Meadows 2008, 77). The general lesson here is resilience cannot be separated from systemic interactions across a variety of scales because if natural disaster hits a location with complex ecological, cultural, social and technical systems interrelating, there will be consequent impacts on the functioning of those systems and human lives which are involved within those interactions (Tweed and Walker 2011).

The CLD in Figure 15 was also used to find potential alternative measures to tackle the problem. The essence here is that a rich structure of many feedback loops working in different ways can restore a system back to normal even after a large perturbation (Meadows 2008, 76). It means more options to supply energy or to mitigate impacts of energy supply shortage enable the communities to cope with the problem.

Those might be the first step for resilience building, but further step is needed for resilience building. The variables of the CLD did not include quantitative data corresponding to the dimensions of the systems attributes. There is also a need of more works to analyze what social aspects can influence the use of energy and resources and vica versa, which is the second systems attribute of resilience in this thesis. Although it was mentioned that cooperation within communities to share limited resources and energy services was important aspect for resilience building in the results of social survey and causal-loop diagramming, more data collection and analysis are needed for deeper understanding. The level of preparation for emergency in terms of energy supply at both municipal and individual level, both technically and socially, is also necessary to be analyzed. Developing resilience assessment framework of the two systems attributes is suggested, which could help policy makers to understand the particular weaknesses in terms of energy supply when natural disasters hit. Table 7 is an example of the framework. Resilience assessment may need to be conducted at individual or community level by using such a framework rather than city level because what need to be improved may vary depending on individuals and areas.

Table 7. Examples of resilience assessment framework

Impacts of energy shortage on life	Degree of impact	Alternative measures	Degree of effectiveness
Lighting	1->5		1->5
Communication with family	1->5		1->5
Heating	1->5		1->5
Drinking water	1->5		1->5
Buying foods	1->5		1->5

Degree of cooperation within a community	**1->5**
Degree of attachment to a community	**1->5**

Moreover, ideally, quantitative data collection and system dynamic modeling and group modeling of causes, impacts and feedbacks of energy supply shortage should be conducted. Stakeholder involvement for group modeling can ensure what alternative measures should be implemented as there are many 'eyes' to look at the problem. These could support policy makers for disaster risk reduction by showing the behavior of the system over time.

4.4.2 Causal Loop Diagram as a Learning Tool and Decision Making Tool for Disaster Risk Reduction

The CLDs potentially can be used as social or individual learning tool for disaster risk mitigation. A participatory causal loop diagramming process can help disaster risk management planners and residents groups sharing their knowledge and learning what the consequences of a large-scaled disaster and the necessary actions would be before they happen, which can often be out of recognition. It is important to emphasize that CLD is not a tool to find solution or to seek optimization, but rather to find leverage points to tackle the causalities of the problem. Learning can result in finding measures as well as understanding inconsistencies and unintended consequences of actions and decisions (Maani and Cavana 2000, 109). Based on learning, they can make decision makings for better preparation in terms of energy supply shortage for disaster risk reduction planning at policy, community and individual level. Senge (1990) argues that systems thinking is the fifth discipline of a "learning organization" that enables us to see things as a whole, of which a learning organization is defined as one "which is continually expanding its ability to create its future."

4.5 Recommendations to Kamaishi

Recommendations for tackling the problem of energy supply shortage in disaster risk management specifically to Kamaishi City can be summarized as follows:

Firstly, the concept of resilience should be discussed and reflected to disaster risk management practice. Resilience is sometimes sacrificed for stability and productivity (Meadows 2008, 77) (i.e. minimizing cost), but it would increase risk of negative outcomes of natural disasters because of ignoring or reducing the ability of communities to cope with them by themselves. Diverse options for energy supply should be prepared so that the risk of energy supply shortage caused by natural disaster would be reduced. When implementing these measures, it is important to consider that risk of disaster varies from area to area as shown in the results of the social survey. Especially, areas with risk to be isolated geographically (e.g. Toni-cho) when the tsunami hit should prepare with some facilities that a community can use together.

Secondly, learning the possible consequence of energy supply shortage caused by earthquake and tsunami by using the results of systems analysis is recommended, which is a practice to build resilience. As discussed above, CLD is a useful learning tool to show the interconnections between factors that people often do not recognize. With recognition of how earthquake and tsunami could happen to the energy supply system in a holistic manner, the city would have better preparedness. Learning process itself would strengthen the social institution including social networks within the communities. Besides, if the city improves measures to cope with the problem, residents would have sense of safety and it will be recognized that Kamaishi is progressing towards a safer city after the tragic event.

Finally, values should be discussed and explicitly described when planning projects and policies towards reconstruction including resilience building, which are based on the discussion on values in sustainable development given by Sen (2004) and the project concept paper of 'eco model city' (Kamaishi City ibidb) that is one of the projects for the reconstruction in relation to energy supply. Values should be discussed well because seeing people in terms of only their needs may give us narrow view of humanity (Sen 2004). Although Sen (2004) welcomes the emerging discussions of sustainable development, he argues that it needs to be considered that people have not only 'needs' but also 'values'. In the project concept paper of 'eco mode city', value aspects in the document are too vague to understand. Without understanding and sharing values behind projects and policies amongst the citizens in Kamaishi, it would be difficult for them to participate in planning and implementation of such a project as well as other social learning activities to build resilience. This is because values are hard to see as discussed in 'four levels of thinking' in Chapter 2. The following argument focuses on the values behind building resilience against earthquake and tsunami in the context of sustainable development of Kamaishi.

Even after the catastrophe and under the risk of unpredictable tsunami disaster, many people have hope and willing to continue living in or to go back to Kamaishi. They grew up and lived in Kamaishi, came to have family, relatives, friends and tight social connections within or with the local communities, and connections to different generations including their ancestors and to those who lost lives by the disaster. Although those values may differ from person to person, as far as there are people who value on living in Kamaishi, we are responsible to sustain or expand safety, sense of security, social connections of the local communities. Building resilience of communities against natural disasters would reduce their risk and strengthen the social institution, which directly contribute to sustaining or expanding them. Two normative values must be emphasized for reasoning resilience building. Firstly, we need to address resilience building with consideration of equity within the current generation such as age, gender and place to live, which means everybody should have equal opportunity to the same or similar standard level of safety. It is important to reemphasize that the results of the social survey showed the difference of energy services in need amongst the three areas. Policy makers in disaster risk management should consider disaster risk is not uniform even in the same city and differs from person to person. Thus, practical measures implemented also varies depending on communities or individuals. Secondly, our generation has responsibility to work for building resilience to expand future generations' well-being because only the current generation can influence later generations (Sen 2004).

5. Conclusion

This thesis addresses the problem of vulnerable energy supply systems when severe natural disaster occurs by studying the case in Kamaishi.

Resilience is an important concept to consider and prepare measures to supply energy in response phase when the existing energy supply system does not function due to devastation. But it needs to be defined carefully for an appropriate application because there are diverse definitions existing and they are too vague to apply to practice. Therefore, resilience is defined as system attributes and corresponding dimensions are set to use in the analysis. Quantitative approach for resilience assessment is recommended.

Causal loop diagramming method contributes to analyzing and visualizing causes, impacts and feedbacks of energy supply shortage due to earthquake and tsunami. The method, together with systems analysis, also helps analyzing potential alternative measures to build resilience of communities in terms of energy supply. In practice, it is expected that CLD will serve as a decision support and learning tool that can be used by both the residents of Kamaishi and the policy makers in preparing future disaster risk reduction plans.

As potential alternative measure to tackle the problem, the concept of decentralized local electricity supply system and some technical measures are proposed. But, social, economic and technological feasibility of the suggested those measures (i.e. off-grid energy generation systems, electric vehicles) requires further research, ideally a set of group modeling workshops with broad stakeholder participation.

References

Ackermann, Thomas., Göran. Andersson., and Lennart. Söder. 2001. "Distributed Generation: a Definition." *Electric Power Systems Research* 57(3): 195–204. doi:10.1016/S0378-7796(01)00101-8.

Adger, W N. 2000. "Social and Ecological Resilience: Are They Related?." *Progress in Human Geography* 24(3): 347-364. doi:10.1191/030913200701540465.

Advisory Committee on Energy and Natural Resources. 2012. *LPG Security based on Lessons from the Great East Japan Earthquake: Towards Building Robust LPG Supply System Against Disasters (in Japanese)*. http://www.meti.go.jp/press/2011/03/20120329003/20120329003-2.pdf.

Alabaster, Jay. 2011. "Tsunami-hit hospital copes with no heat, light." *msnbc.com*, March 20. http://www.msnbc.msn.com/id/42182156/ns/health-health_care/t/tsunami-hit-hospital-copes-no-heat-light/.

America, Latin. 1999. "Our Common Journey: A Transition Toward Sustainability." *The Journal of school health* 1196(1): 1-14. doi:10.1111/j.1749-6632.2009.05398.x.

Anderies, John M., Marco A. Janssen., and Elinor. Ostrom. 2004. "A Framework to Analyze the Robustness of Social-ecological Systems from an Institutional Perspective." *Ecology And Society* 9(1): 18. http://www.public.asu.edu/~majansse/pubs/es2004a.pdf.

Arnell, N W., M G R Cannell., M Hulme., R S Kovats., J F B Mitchell., R J Nicholls., M L Parry., M T J Livermore., and A White. 2002. "The Consequences of CO2 Stabilisation for the Impacts of Climate Change." *Climatic Change* 53(4): 413-446. doi:10.1023/A:1019939003210.

Bryman, Alan. 2008. *Social Research Methods.* New York: Oxford University Press Inc.

Carlson, J M., and John. Doyle. 2002. "Complexity and Robustness." *Proceedings of the National Academy of Sciences of the United States of America* 99(Suppl 1): 2538-2545. doi:10.1073/pnas.012582499.

Carpenter, Steve., Brian. Walker., Marty. Anderies J., and Nick. Abel. 2001. "From Metaphor to Measurement: Resilience of What to What?." *Ecosystems* 4(8): 765-781. DOI: 10.1007/s10021-001-0045-9.

Chinese Taipei. Ministry of Economic Affairs (MOEA), Energy Commission. 2002. *Earthquake Disaster Management of Energy Supply System of APEC Member Economies.* Taipei: MOEA, Energy Commission. http://earthquake.tier.org.tw/documents/sf01-10.pdf.

Clark, William C., and Nancy M Dickson. 2003. "Sustainability Science: the Emerging Research Program." *Proceedings of the National Academy of Sciences of the United States of America* 100(14): 8059-8061. http://www.pnas.org/content/100/14/8059.full.pdf+html.

Donella, Meadows H. 2009. *Thinking in Systems.* London: Earthscan

Dovers, Stephen R., and John W. Handmer. 1992. "Uncertainty, Sustainability and Change." *Global Environmental Change* 2(4): 262-276. doi:10.1016/0959-3780(92)90044-8.

Elkhattam, W. 2004. "Distributed Generation Technologies, Definitions and Benefits." *Electric Power Systems Research* 71(2): 119-128. DOI:10.1016/j.epsr.2004.01.006

Farooque, M., and H C. Maru. 2001. "Fuel Cells-the Clean and Efficient Power Generators." Proceedings of the IEEE 89(12): 1819-1829. doi:10.1109/5.975917.

Feinstein, Charles D., Ren. Orans., and Stephen W. Chapel. 1997. The Distributed Utility: A New Electric Utility Planning and Pricing Paradigm.*Annual Review of Energy and the Environment* 22(1): 155-185. doi:10.1146/annurev.energy.22.1.155.

Folke, C. 2006. "Resilience: The Emergence of a Perspective for Social–ecological Systems Analyses." *Global Environmental Change* 16(3): 253-267. doi:10.1016/j.gloenvcha.2006.04.002.

Folke, Carl., Steve. Carpenter., Thomas. Elmqvist, Lance. Gunderson., C S. Holling., and Brian. Walker. 2002. "Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations." Ed. Environmental Advisory Council. *Ambio* 31(5): 437-440.

http://www.ncbi.nlm.nih.gov/pubmed/12374053.

Forrester, J W. 1961. *Industrial Dynamic*. Boston: MIT press.

Gibbons, Michael. 1994. *Innovation and the Developing System of Knowledge Production*. Trinational Summer Institute on Innovation, Competitiveness, and Sustainability in North America. August 14–20

Haraldsson, Hördur V. 2005. "Developing Methods Methods for Modelling Procedures in System Analysis and System Dynamics. PhD Diss., Lund University.

Hata, Yoichiro "Supplying Electricity to a Household for 2 days from EV (Japanese)." *MONOist*. http://monoist.atmarkit.co.jp/mn/articles/1108/02/news085.html. ITMONOist 2nd August, 2011

Hjorth, P., and A. Bagheri. 2006. "Navigating towards Sustainable Development: A System Dynamics Approach." *Futures* 38(1): 74-92. doi:10.1016/j.futures.2005.04.005

Holling, C S. 1973. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics*. 4(1): 1-23. http://www.iiasa.ac.at/Admin/PUB/Documents/RP-73-003.pdf.

Holling, C S., and Gary. K Meffe. 1996. "Command and control and thepathology of natural resource management." *Conservation Biology*. 10(2): 328–337. doi:10.1046/j.1523-1739.1996.10020328.x.

Hosomi, Masaaki. 2011. "Safety and Security of Japanese Society Threatened by Unpredictable Earthquake and Tsunami: Overcoming the Crisis with Japanese Wisdom and Cheer." *Clean Technology and Environmentanl Policy.* 13(3): 415-416. doi: 10.1007/s10098-011-0392-y.

Hsu, Chia-Sui. 2011. "Resilience in Space: An experimental analysis of resilience in urban flood management in the Taipei Basin." Master diss., Lund University. http://www.lumes.lu.se/database/alumni/09.11/Thesis/Hsu_Chia%20Sui%20(Jessica)_Thesis_2011%20.pdf.

International Energy Agency (IEA). 2002. *Distributed Generation in Liberalised Electricity Markets Distributed Generation in Liberalised Electricity Markets*. Ed. Anonymous. OECD/IEA: 125. http://www.iea.org/textbase/nppdf/free/2000/distributed2002.pdf.

International Federation of Red Cross and Red Crescent Societies (IFRC). 2004. *World Disasters Report 2004: Focus on Community Resilience.*

International Strategy For Disaster Reduction Isdr, Null. 2009. "Terminology on Disaster Risk Reduction". *International Strategy for Disaster Reduction ISDR*. United Nations International Strategy for Disaster Risk Reduction. http://www.unisdr.org/eng/library/UNISDR-terminology-2009-eng.pdf.

International Union for Conservation of Nature (IUCN). 2006. *The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century*. Report of the IUCN Renowned Thinkers Meeting. Hotel Uto Kulm, Zurich. January, 29-31, 2006. http://cmsdata.iucn.org/downloads/iucn_future_of_sustanability.pdf.

Japan. Agency for Natural Resources and Energy (ANRE). 2011a. *Energy White Paper 2011 (in Japanese)*. http://www.enecho.meti.go.jp/topics/hakusho/2011/index.htm.

Japan. Agency for Natural Resources and Energy (ANRE). 2011b. *Oil Supply in the Great East Japan Earthquake* (in Japanese). http://www.bousai.go.jp/3oukyutaisaku/higashinihon_kentoukai/5/sigen.pdf.

Japan. Ministry of Economy, Trade and Industry (METI). 2011a. *Overview of Electricity Outage in Wide Areas Caused by the Earthquake on March 11th, 2011 (Japanese)*. Sub Referential Material for the Nineth Expert Meeting for Lessons from the Great East Japan Earthquake and Earthquake and Tsunami Countermeasures, September 10, 2011. Tokyo: Central Disaster Prevention Council. http://www.bousai.go.jp/jishin/chubou/higashinihon/9/sub2.pdf.

Japan. National Police Agency of Japan, Emergency Disaster Countermeasures Headquarters. 2012. *Damage Situation and Police Countermeasures associated with 2011 Tohoku District - off the Pacific Ocean Earthquake, March 14, 2012*. National Police Agency of Japan.

http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf.
Kamaishi City. Ibida. Kamaishi City Hopepage. http://www.city.kamaishi.iwate.jp/
Kamaishi City. Ibidb. *The Kamaishi City Eco Model Project: The Most Progressive Small City in Japan: Kamaishi's New Challenge*. http://futurecity.rro.go.jp/english/forum/kamaishi.pdf.
Kamaishi City. 2009. *Kamaishi City Health and Welfare Plan for Elderly People/The 4th Plan for Care Insurance in Kamaishi City (in Japanese)*. http://www.city.kamaishi.iwate.jp/index.cfm/10,8998,c,html/8998/01.pdf.

Kamaishi City. Disaster Countermeasures Office. 2011. *East Japan Earthquake and Tsunami: Current situation of damage (November 18th, 2011)(in Japanese)*. http://www.city.kamaishi.iwate.jp/index.cfm/10,19080,c,html/19080/20120213-141801.pdf.
Karger, Cornelia R., and Wilfried. Hennings. 2009. "Sustainability Evaluation of Decentralized Electricity Generation." *Renewable and Sustainable Energy Reviews* 13(3): 583-593. doi:10.1016/j.rser.2007.11.003.
Kates. Robert W., William C. Clark., Robert. Corell., J Michael. Hall., Carlo C. Jaeger., Ian. Lowe., James J. Mccarthy., et al. 2001. "Sustainability Science." *Science* 292(5517): 641-642. doi:10.1016/S0140-6736(08)61659-1.
KDDI Corporation. Ibid. "Countermeasure for Natural Disasters (Japanese)." *au*. http://www.au.kddi.com/notice/saigai_torikumi/gaiyo/index_1.html.
Klein, Richard J T., Robert J. Nicholls., and Frank. Thomalla. 2003. "Resilience to Natural Hazards: How Useful is This Concept?." *Global Environmental Change Part B Environmental Hazards* 5(1-2): 35-45. doi:10.1016/j.hazards.2004.02.001.
Komiyama, Hiroshi., and Kazuhiko. Takeuchi. 2006. "Sustainability Science: Building a New Discipline." *Sustainability Science* 1(1): 1-6. http://www.environmental-expert.com/Files%5C6063%5Carticles%5C15092%5Cart13.pdf.
Lele, Sharachchandra M. 1991. "Sustainable development: A critical review." *World Development.* 19(6): 607-621. http://www.sciencedirect.com/science/article/B6VC6-4692282-3/2/e21de053652cd86f65400efc7543bbe5.
Lund University. 2008. Applied Systems Analysis & System Dynamics Group. *Lund University*. http://www.lth.se/asasd.
Maani, Kambiz E., and Cavana. Robert Y. 2007. *Systems Thinking and Modelling - Understanding Change and Complexity*. 2nd edition. Auckland: Prentice Hall.
Manyena, Siambabala Bernard. 2006. "The concept of resilience revisited. Disasters." 30(4): 433-450. http://www.ncbi.nlm.nih.gov/pubmed/17100752.
Manyena, Siambabala Bernard. 2006. "The Concept of Resilience Revisited." *Disasters* 30(4): 433-450. http://www.ncbi.nlm.nih.gov/pubmed/17100752.
Martens, Pim. 2006. "Sustainability: Science or Fiction?." *Sustainability: Science, Practice, & Policy*. 2(1): 36-41. http://sspp.proquest.com/static_content/vol2iss1/communityessay.martens.pdf.
McCurry, Justin. 2011. "Japan: the aftermath." *THE LANCET*, March 26. http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(11)60413-3/fulltext.
McKenzie, Stephen. 2004. "Social Sustainability: Towards Some Definitions." *Magill Hawke Research Institute Working Paper Series* 27(27): 1-29.
Mizuho Information and Research Institute. 2012. *Investigation on LPG Stable Supply based on the Experience of the East Japan Great Eaarthquake and Tsunami (Japanese)*. http://www.meti.go.jp/press/2011/03/20120307002/20120307002.html.
Murakami, Yoshiro., and Edward, Fukui. 2011. *'Smart Nippon' Sengen: Keizai Fukko No Tameno Energy Policy (Japanese)*. Tokyo: ASCII MediaWorks Inc.
National Tsunami Hazard Mitigation Program (NTHMP) Steering Committee. 2001. *Designing for Tsunamis:*

Seven Principles for Planning and Designing for Tsunami Hazards. NTHMP) Steering Committee. http://nthmp-history.pmel.noaa.gov/Designing_for_Tsunamis.pdf.

Nishimura, Michinari. 2004. *Systems Thinking* Nyumon *(Japanese)*. Tokyo: Nihon Keizai Shinbun Shuppan-sha.

Nohara, Masaru. 2011. "Impact of the Great East Japan Earthquake and Tsunami on Health, Medical Care and Public Health Systems in Iwate Prefecture, Japan, 2011." *Western Pacific Surveillance and Response Journal.* 2(4). http://www2.wpro.who.int/wpsar/archives/archives_2(4)2011_lf_nohara.htm.

Onoue, Kiyoaki., Yukitaka. Murakami., Petros. Sofronis. 2012. "Japan's Energy Supply: Mid-to-long-term Scenario - A Proposal for a New Energy Supply System in the Aftermath of the March 11 Earthquake." *International Journal of Hydrogen Energy* 37(10): 8123-8132. doi:10.1016/j.ijhydene.2012.02.096

Pepermans, G., J .Driesen., D. Haeseldonckx., R. Belmans., and W. Dahaeseleer. 2005. Distributed Generation: Definition, Benefits and Issues. *Energy Policy* 33(6): 787-798. doi:10.1016/j.enpol.2003.10.004.

Pimm, Stuart L. 1991, *The Balance of Nature? Ecological Issues in the Conservation of Species and Communities*. Chicago: University of Chicago Press.

Resilience Alliance. 2012. Resilience Alliance - Key concepts - Resilience. *resallianceorg*. http://www.resalliance.org/index.php/resilience

Sasahara, Eiji. 2011. "Impacts of the East Japan Earthquake and Tsunami towards Governance, Risk and Compliance in Healthcare IT" in *Synthesis Journal 2011*, edited by Information Technology Standards Committee (ITSC). Singapore: ITSC. http://itsc.org.sg/pdf/2011/Section4_Article1_021111.pdf.

Sen, Amartya. 2004. "Why We Should Preserve the Spotted Owl." *London Review of Books* 26(3): 1-4. http://www.lrb.co.uk/v26/n03/print/sen_01_.html.

Senge, Peter M. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization*. New York: Doubleday/Currency.

Shinoda, Yukio., Hideo. Tanaka., Atsushi. Akisawa., and Takao. Kashiwagi. 2011. "Evaluation of the Plug-in Hybrid Electric Vehicle Considering Learning Curve on Battery and Power Generation Best Mix." *Electrical Engineering in Japan* 176(2): 31-40. doi:10.1002/eej.21098.

Smit, Barry Canada., M Skinner. Canada., and J Wandel. Canada. 2003. "Adaptation to Climate Change in the Context of Sustainable Development and Equity." Ed. J J McCarthy, O F Canziani, N A Leary, D J Dokken, and K S White. *Sustainable Development* 8(9): 9–28.

Softbank Mobile Corporation. Ibid. "Measures to Prepare for Disasters." SoftBank. http://www.softbankmobile.co.jp/ja/initiatives/disaster/guarding/.

Stokes, Donald E. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington.D.C: Brookings Institution Press.

The Federation of Electric Power Companies of Japan (FEPC). ibid. The Trend of Daily Electric Power Consumption per Household (Japanese). *FEPC*. http://www.fepc.or.jp/present/jigyou/japan/index.html.B44.

Tweed, Fiona., and Walker. Gordon. 2011. "Some Lessons for Resilience from the 2011 Multi-disaster in Japan." *Local Environmen.* 16(9): 937-942. doi:10.1080/13549839.2011.617949.

United Nations International Strategy for Disaster Risk Reduction (UNISDR). 2005. *Hyogo Framework for 2005–2015: Building the Resilience of Nations and Communities to Disasters*. http://www.unisdr.org/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf.

Waller, M A. 2001. "Resilience in ecosystemic context: evolution of the concept." *The American journal of orthopsychiatry* 71(3): 290-297. http://www.ncbi.nlm.nih.gov/pubmed/11495331.

Witze, A. 2012. "Making Waves." Science News. Vol.181 no.4. February 25. http://www.sciencenews.org/view/feature/id/338301/title/Making_Waves.

World Commission on Environment and Development (WCED). 1987. *Our Common Future*. Ed. G H Brundtland. Oxford paperbacks. Vol. Report of. Oxford University Press. http://www.un-documents.net/wced-ocf.htm.

Yokoyama, Ryuichi., Kenji. Iba., and Kaoru. Koyanagi. 2011. *Saigaini Tsuyoi Electricity Network: Smart Grid No Kiso Chishiki (Japanese)*. Tokyo: Wasedai Daigaku Shuppan-sha.

Appendix A. Raw Data of the Semi-structured Interviews with 97

*(E) implies an interviewee living in an emergency

No	Interview Area	Gender	Age	Energy Service in Need	Place to evacuate	Other comments
1	Unosumai-cho	F	50	The biggest problem was cooking and telephone call. I boiled water by using a kerosene heater because tank of LP gas (usually used for cooking) was washed out by the tsunami. I could not flash the toilet, but I could use a conventional style toilet in the temple in the mountain. Freshwater was brought from outdoor.	Stayed a few days in the near mountain, and came back home.	
2	Unosumai-cho	M	70	It was snowing, blowing and cold when I stayed in the mountain right after the disaster. I warmed myself with outdoor fire, and used it for cooling as well. I used candles for lighting.	Stayed a few days in the near mountain, and moved to the shelter in Ohata-cho in Kamaishi.	I picked and used foods that were float out by the tsunami.
3	Unosumai-cho	F	80	I tried warding off the coldness with futon (Japanese-style bedding) as many as possible because it was too cold. I could not listen to the alert from the community wireless system.	Stayed a few days in the near mountain, and came back home.	While some people went to a shelter, I stayed at home and stayed with 10 evacuees who lost their houses. So I did not go to a shelter.
4	Unosumai-cho	F	60	There were stoves and heating oil, so heating was not a problem.	Stayed in the Education Centre for the first 10 days, and stayed 40 days in the shelter in Kosano-cho in Kamaishi.	Since water and electricity supply were not restored till the 50th day after the disaster, I did not come back home until then. Another reason is I heard that there were suspicious people skulking around the neighborhood and I was anxious of coming back.
5	Unosumai-cho	F	60	I lacked of gasoline and the road was shut off. The problem was I could not transport some educational materials to Morioka City, which was my business. It was important because the new school year was going to begin at that time.	Stayed in Morioka City first, and in the shelter in Kasshi-cho after the road was opened.	
6	Unosumai-cho	F	50	I could not boil water for bathing because of electricity outage. Another problem was communication. I used charcoal for cooking and got water by melting snow.	Stayed inside the car at high point, and came back home.	Water supply restarted in the end of May.

7	Unosumai-cho	F	60	Could not cook, light and watch TV. Instead of TV, I used a radio function of my cell-phone. I gathered with my friends for heating by stove. The problem was flushing toilet.	Stayed at home 1 day and in the shelter (Kamaishi Junior High school) for 2 days, and came back home.	
8	Unosumai-cho	F	50	I could not use telephone including mobiles, and used candles for lighting because of blackout. I had sufficient gasoline since I filled it before the disaster, but I could not drive because the road was shut off. I parked my car on the highway first, but drove it back after the road was opened because I was anxious of gasoline stolen and security. Another problem was flushing toilet because water was not supplied. I bathed in a public bath.	Stayed 2 days in the shelter (Kamaishi Junior High school), and came back home.	
9	Unosumai-cho	M	70	There was gas left, so I could cook. I used a lantern for lighting and TV was off. Electricity supply restoration here was late compared with other areas in Unosumai-cho and Ryoishi-cho, so I told that to the municipality.	Home	
10	Unosumai-cho (E)	F	60	All the electronics were not available such as bathing and communication. I used kerosene stove for heating and LP gas for cooking (but, once for a few days in order for saving gas).	Sister's home	
11	Unosumai-cho (E)	F	40	There were sufficient number of stoves and heating oil. The construction company near by the shelter brought a large power generator for us and we could use electricity (only in the night to save fuel for power generation).	Shelter (Kuribayashi Elementary School)	
12	Unosumai-cho (E)	M	70	There was no particular problem because both heating oil and electricity was available.	Shelter in Nakazuma-cho	
13	Unosumai-cho (E)	M	60	Lighting and communication by mobile phone. Flushing toilet.	Shelter (Kasshi Junior High school)	Luckily I could evacuate quickly after the disaster.

14	Unosumai-cho	M	80	I could not use heating facilities and it was cold though I put futon on me. There was lack of heating oil for about 20 days. I went to outside to get freshwater as toilet could not be flushed, but I also needed to save using gasoline for transporting water. I did not know when water supply would restart.	Stayed 2 days in shelter, and came back home.	
15	Unosumai-cho	F	60	I could not cook and use a stove and a kotatsu (a wooden table frame covered by a futon with a heat source) for heating.	Home	
16	Unosumai-cho	F	60	I could not cook, and lacked heating oil for warming water for bathing. I brought freshwater from a mountain and washed clothes in the river.	Home	Worked for making rice balls for 2 days after the disaster as volunteer.
17	Unosumai-cho	M	20	Community wireless system was broken by the tsunami and I could not hear alert. I guess there were those who could not evacuate because of it.	Family home (Kuribayashi-cho)	
18	Unosumai-cho	M	80	Heating facilities were not usable because of blackout.	Home	Those who were in a shelter had foods distributed and with priority, and flashlight was also distributed to only shelters. I should have gone to a shelter to get those. I met some visitors who came to ask questions for their survey, but I am not sure their results are reflected to something. It i better to tell survey results to decision makers rather than just doing survey.
19	Unosumai-cho (E)	F	60	I could not go buying foods because of lack of gasoline. I queued near the gas station in midnight to fill gas in the next morning. Another problem was lack of heating oil and there was no heating. I could cook with LP gas though there was electricity outage.	1 day in Ozuchi High school, and went to husband's family home.	
20	Unosumai-cho (E)	M	60	It was very cold because of no heating and no futon.	3 days in mountain, 3 days in shelter, and went to Aomori Prefecture.	

21	Unosumai-cho (E)	F	70	Not particular.	Shelter in Ozuchi, and moved to daughter's home.	
22	Unosumai-cho (E)	F	30	Communication.	3 days in mountain, and moved to shelter in Ozuchi.	
23	Unosumai-cho (E)	M	60	I could not go anywhere because of lack of gasoline.	Private residence in Kuribayashi-cho, and moved to brothers' home.	
24	Unosumai-cho (E)	F	70	I was in trouble overall, but particularly with no electricity and no telephone communication. I did not have sufficient heating oil and it was cold. Gasoline was lacked and the road was blocked, so I needed to go a long way round through Tono City.	Dauter's home in Kuribayashi-cho, and son's house in Odaira-cho	
25	Unosumai-cho (E)	F	60	Heating and lighting facilities were not usable because of blackout. Toilet could not be flushed, so I supplied freshwater by passing it from passing to person outdoor.	Private residence at high point for 3 days, and moved to shelter (Omatsu Elementary School)	I heard that mountain faire was coming from Ozuchi side (north of Kamaishi).
26	Unosumai-cho (E)	M	20	The problem was I could not get information. I used a mobile phone as alternative.	Relative's home	
27	Unosumai-cho (E)	F	40	Could not cook because of blackout. All the facilities (including cooking and heating) needed electricity. were appliance. There was not lighting and candles were lacked as well, so I tried eating dinner early, before it became dark.	Relative's home in Kamaishi	
28	Unosumai-cho (E)	M	60	Though my wife was ill, I could not bring her to hospital because of lack of gasoline. But Japan Red Cross assisted me. I also could not go buying foods.	Shelter in Sotoyama in Unosumai-cho, and relative's home	
29	Tenjin-cho (E)	F	80	I was in Morioka when the tsunami hit the city, and I was in trouble with lack of gasoline to go to Kamaishi.	Daughter's home in Kmorioka City	I lost 10 friends by the tsunami, and became alone. It is difficult to go to hospital in Morioka City by myself, so my daughter comes to pick me up from Morioka City.
30	Tenjin-cho (E)	F	20	I could not go buying foods because of lack of gasoline.	Family's home in Kasshi-cho	

31	Tenjin-cho (E)	F	60	I could not flush toilet and could get information.	Shelter (Nozomi Hospital)	
32	Tenjin-cho (E)	F	70	Not particular except for the elevator in the hospital did not work.	Shelter (Nozomi Hospital)	My son was covered by the tsunami and he was cold. The self-defense force came helped him.
33	Tenjin-cho (E)	F	50	I could not go back to my home to check the situation because of lack of gasoline. It was cold because of no heating.	Office in Noda-cho	
34	Tenjin-cho (E)	F	70	I could not communicate because my mobile was not available. I was injured by the tsunami and could not move.	Private residence in Higashimae-cho	
35	Tenjin-cho (E)	F	60	Not particular because there were stoves and heating oil.	Shelter (Senju In Temple)	
36	Tenjin-cho (E)	F	80	Not particular. There were stoves.	Shelter (Municipal Office for 1 day, and Nakazuma Elementary School)	
37	Tenjin-cho (E)	F	70	I could not bathe and could not wash my head. There were stoves in the shelter, but it seemed that people around the stoves occupied them.	Private residence in Nakazuma for 1 day, and shelter (Kogawa Gym)	
38	Tenjin-cho (E)	F	80	I could not use telephone to confirm the safety of people.	Private residence at the mountain side in the city	
39	Tenjin-cho (E)	F	70	Not particular.	Morioka City	
40	Tenjin-cho (E)	F	50	It was cold without heating because of blackout. Could not flush toilet, neither.	1 day at home, and moved to shelter (Municipal Office 1 day, Kamaishi Junior High school 3 months)	It was convenient that there were stoves and power generator in Kamaishi Junior High school.
41	Tenjin-cho (E)	F	80	There was heating and it was fine.	Shelter (Nozomi Hospital)	
42	Tenjin-cho (E)	M	30	No lighting and heating. But both stoves and power generator were introduced after some time in the shelter.	Shelter (Kamaishi Junior High school)	
43	Tenjin-cho (E)	M	80	It was not too bad. There were emergency electricity generators, stoves. Water was also supplied.	Shelter (Kamaishi Junior High school)	

44	Tenjin-cho (E)	F	60	Could not go buying foods because of lack of gasoline. There were some stoves.	Shelter (Kamaishi Junior High school)	
45	Tenjin-cho (E)	F	30	I needed to drive to confirm the safety of people, but gasoline was lacked. Besides, I could not call as my mobile phone did not work.	Shelter (Municipal Office)	
46	Tenjin-cho (E)	M	40	Nothing particular. Since I am a fisherman, I used a fishing boat for evacuation for about a month.	Fishing boat	
47	Tenjin-cho (E)	M	70	No lighting, no flushing toilet. There were stoves and a power generator.	Shelter (Nakazuma Junior High school)	
48	Tenjin-cho (E)	F	40	Could not cook, and no flushing toilet. Though I brought freshwater from a mountain, I guess those who need baby milk or need to take drugs, like babies and elderly people, were in trouble without water supply. I store water in bottles and prepare a flashlight for emergency.	Shrine in a mountain, and home	
49	Tenjin-cho (E)	F	60	Nothing particular.	In mountain for 2 days, and moved to a shelter in Unosumai-cho	
50	Tenjin-cho (E)	F	40	No flushing toilet because of lack of water and drinking water. I melted snow to make it water. The town gas supply was stopped, so I could not cook.	Family home	
51	Tenjin-cho (E)	F	-	I was hospitalized in Steel Memorial Hospital. It was dark in the night and cold without stoves, but I was fine when I put futon on me.	Steel Memorial Hospital, and shelter (Nakazuma Junior High school)	
52	Tenjin-cho (E)	F	50	There were stoves and a power generator, but used of heating oil and light oil were limited. The neighbors gave us heating oil.	Shelter (Sekioji Temple)	
53	Tenjin-cho (E)	F	80	Could not confirm the safety because telephone did not work.	Private residence in Higashimae-cho	I was happy since we helped each other.
54	Tenjin-cho (E)	M	70	It was cold as heating facilities did not work due to blackout. No water supply. I could not cook and boil water because the town gas supply was stopped.	2^F at home	Kamaishi Gas Corporation supplied me LPG tanks after May.
55	Tenjin-cho (E)	F	80	Nothing particular since there were stoves and a power generator.	In mountain, and shelter (Senjuin Temple, Nakazuma Junior High school).	

56	Tenjin-cho (E)	F	60	I needed to find my husband from Unosumai-cho, but I lacked gasoline. As alternative way, I borrowed a bike. There was a power generator in the shelter.	Shelter (Kuribayashi Elementary School)	
57	Tenjin-cho (E)	F	60	There were heating oil and a power generator. We used them by saving fuels.	Shelter (Kamaishi Junior High school)	
58	Tenjin-cho (E)	M	60	It was cold without heating.	Shelter (Senju In Temple)	
59	Tenjin-cho (E)	M	60	Nothing particular	Shelter (Senju In Temple)	
60	Tenjin-cho (E)	F	80	Nothing particular. I did not feel cold since there were 4 or 5 stoves. It was blackout in the beginning, but later a power generator came.	Shelter (Kamaishi Junior High school, Ohata-cho)	
61	Tenjin-cho (E)	F	60	I could not cook because of blackout. I burned the wreckage of the buildings for cooking. It was cold without heating.	Private residence in Higashimae-cho	
62	Tenjin-cho (E)	M	60	No stoves and it was cold. No communication with phones.	The second floor at home, and shelter (Kamaishi Junior High school)	
63	Toni-cho	F	60	I was anxious of not communicating with others because I could not use the telephone. I remember that telephone was not available till May, 2011. The electricity did not come back on 25th March, so I used cells and candles instead.	Stayed in my relative's house in Toni-cho and came back home 10 days after the tsunami.	I could boil water and cook because LP gas was available. Only mobile phones contracted with AU (one of the major mobile communication service companies) were not available, but it was not because of electricity outage.
64	Toni-cho	F	70	I could not heat a bath. Cannot do anything without electricity.	Home	I could cook since gas was available. I think electricity fee is too expensive.
65	Toni-cho	M	80	I could not get information since the TV did not work, and I had no idea what was happening because of the disaster. I supposed to get heating oil from the local fishermen community, but they were affected by the tsunami and there was no supply of heating oil. Heating oil and gas were supplied by private organizations.	Home	

66	Toni-cho	F	80	My grandchild helped me lighting.	Home	It was hard as my body did not move well.
67	Toni-cho	F	60	I used a portable light. I felt scary and was anxious because I could not see whether tsunami approaches because of the darkness.	Stayed in the office in the same area for 2 days and came back home.	I thought it was convenient that Kerobe (a part of Toni-cho) had a emergency electricity generator. After the disaster, I thought that a conventional lamp that I used long time ago may be useful. But, such a concern is being forgotten 11 months after the disaster.
68	Toni-cho	F	60	Due to electricity outage, I could not communicate with my relatives. So, my brothers in Tokyo and Saitama worried about me and visited here. It was cold but heating did not work, so I borrowed a stove, which worked well because I had enough heating oil stock enough.	Home	
69	Toni-cho	F	60	It was trouble that water supply stopped. I could not cook due to both electricity outage and gas supply stopped.	Shelter (Toni-cho)	
70	Toni-cho	F	70	Water supply stop was the biggest trouble. I could cook because gas was available. Due to the electricity outage, I felt trouble with no heating and kotatsu (a wooden table frame covered by a futon with a heat source). One of my family members could not walk and could not ride a car to go bathing either.	Shelter in the first 3 days, and came back home.	
71	Toni-cho	F	10	I could not confirm the safety of people because communication tools (e.g. TV and phone) were not available. I used the conventional stove for heating, but its efficiency was too low and it was still cold. I picked up a pan flown by the tsunami and used it for cooking.	Wooden small building owned by relative	The roads were closed and I could not move to other areas.
72	Toni-cho	F	60	Heating and lighting. I could manage using water because the water supply car came.	Relative´s home	

73	Toni-cho	M	60	The biggest trouble was heating. My home uses only electricity for energy supply, but not gas. So I could not boil warm water for bathing. I used a LED light for squid fishing, which lasted for about a half month. The fuel for emergency electricity generator was brought from the inland area in Iwate Prefecture. I managed water supply since there was a fresh water source near here.	Relative´s home	
74	Toni-cho	F	70	I could not boil water for a few days. Heating was not available due to the electricity outage and cooking facilities were broken because they got wet with the tsunami.	The 2nd floor at home	
75	Toni-cho	F	70	I burned wood for cooking and heating. The heating facility and 5 cylinders of heating oil were washed out by the tsunami. Getting drinking water was also a problem. A water supply car came a month after the disaster.	Junior high school for a night, and came back home (2F)	
76	Toni-cho	F	80	The heating facility was washed out, but I had a oil stove instead. So I used it for heating and boiling water. Another problem was communication with people because the phone did not work.	Stayed at home for the first 3 days, and daughter´s home in Noda-cho for a month.	
77	Toni-cho	M	50	I used batteries and candles for lighting. LPG was available and I could cook.	Relative´s home	After electricity was back, only satellite TV worked for a while.
78	Toni-cho	M	40	On the day the disaster hit the area, there was no lights and sounds. I felt scary with the silence. I just went to bed because of no lighting. It took 3 weeks until electricity came back. The problem was no heating and I wore many layers. Another problem was no communication. If I could use a mobile at least, I might be able to tell my sister to evacuate and she could survive.	Shelter on the first day, and came back home.	The roads were closed and Toni-cho was isolated geographically. So I could not move to other areas even though I had gasoline.

79	Toni-cho	M	40	The biggest problem was no information because TV and radio did not work. So I could not know when the lifeline would be restored. I could not hear even the alert from the community wireless system. Even after the restoration, I cannot listen to the local community FM and cannot know well about the local news because of the geographical location of Toni-cho.	Shelter in the first 3 days, and came back home.	It is difficult to stay in a shelter where many people gather with children, so I came back home soon.
80	Toni-cho	M	50	The problem was no water supply. I drove a truck to get water twice a day. Other problems were heating and lighting. I did not have even a candle. LPG was available.	Relative´s home for the first 3 days and came back home (2F)	
81	Toni-cho (E)	F	40	Cooking and warming water for bathing.	Parent´s home in Hongo (a part of Toni-cho)	
82	Toni-cho (E)	F	70	It was too cold when going to bed. I tried finishing eating when it was bright, and used candles for lighting.	Relative´s home in Toni-cho	
83	Toni-cho (E)	M	60	It laster about 19 days to light with only one candle. I could not go buying foods due to lack of gasoline and did not enough foods. I shared a car with my neighbors to save gasoline and went to Tono City (next to Kamaishi City) for buying foods. I could not use phones for about a week and worried. I could listen to radio broadcasting only at night.	Relative´s home in Toni-cho	
84	Toni-cho (E)	F	70	There were cases of stealing heating oil and gasoline. The problem was no communication (phones and mobiles). The satellite phone in the downtown was available, but there was a long queue for it.	-	I heard that residents in Kerobe (a part of Toni-cho) used lights for squid fishing. I think they are united (perhaps because many of them are relatives and know each other well. They ate seafood stored in the fridge. We did not have many problems between neighbors in this area either since we knew each other well.

85	Toni-cho (E)	M	40	I needed to bring my child to the hospital, but there was not enough gasoline remained. So I asked someone to give me gasoline. Gasoline was supplied in the downtown in the city. I put hot water into a bottle and used it for warming my body under the blanket.	Relative´s home (Katagishi, a part of Toni-cho)	
86	Toni-cho (E)	F	50	The biggest problem was heating due to the electricity outage. Water supply was also problem.	My parents' home in Koshiramhama (a part of Toni-cho)	
87	Toni-cho (E)	F	50	I could not access information and could not use heating facilities.	Shelter on the first day, and climbed the mountain to go to my brother´s home in the city.	
88	Toni-cho (E)	F	70	I went to the downtown to supply heating oil three times because it was too cold and the stock of heating oil was not enough. Gasoline supply, too. I got fresh water from the mountain and boiled it.	Neighbor´s home	
89	Toni-cho (E)	M	50	I could not go buying foods because of lack of gasoline though there was enough food stock remained. Since the refrigerator did not work due to electricity outage, I ate from the foods that were easy to be rotten.	Relative´s home in Ofunado City (next to Kamaishi City)	
90	Toni-cho (E)	F	50	The biggest problem was no lighting. I got freshwater from a mountain.	My husband´s parents home in Katagishi (a part of Toni-cho)	
91	Toni-cho (E)	F	50	I had to walk because there was not enough gasoline for driving. I could cook, but boiling facility for warming water for bathing.	Relative´s home in Katagishi (a part of Toni-cho)	
92	Toni-cho (E)	F	70	Without water, I could not cook. I could not bathe, either.	Friend´s home in Koshirahama (a part of Toni-cho)	
93	Toni-cho (E)	M	30	I could not communicate by phone due to the electricity outage. Without heating oil, I could not use the heating stove.	Relative´s home in Koshirahama (a part of Toni-cho)	
94	Toni-cho (E)	M	50	It was too cold without heating. Another problem was I could not five without enough gasoline.	Sister's home in Koshirahama (Toni-cho)	

95	Toni-cho (E)	M	60	Heating and cooking due to the electricity outage. I ran out of batteries and could not use the radio anymore. I burned woods for heating. It was like the old life style long time ago.	Friend´s home in Koshirahama (a part of Toni-cho)	Nothing was available because everything became convenient
96	Toni-cho (E)	F	70	It was too cold without heating. I worried about the amount of gasoline. I tried driving to find my brother who when I heard he was dead, but had to get gasoline from my friend. I went to Heita-cho for bathing.	Daughter's home in Hongo (a part of Toni-cho)	It became convenient, but turned to be inconvenient. A portable light for emergency was useful. After the disaster, I try to keep it all the time.
97	Toni-cho (E)	F	60	The old man was injured by the tsunami, but I could not bring him to hospital because the road was closed. Besides, gasoline was lacked and there was a long queue in front of the gas station, so it was difficult to supply. Heating oil was not enough either and I could not cook and heat. Another problem was in flushing water in toilet.	Relative´s home in Koshirahama (a part of Toni-cho), and then moved to Sadanai-cho in the city	

Appendix B. Quantitative Data of the Interviews with 97 Residents

*(E) implies an interviewee living in an emergency

No	Interview Area	Gender	Age	Energy service in Need											Place to evacuate
				Heating	Communication/Information	Water		Cooking	Lighting	Mobility			Bathing	Not particular	
						Toilet	Others			Buying Foods	Hospital	Others			
1	Unosumai-cho	F	50		1			1							Outside
2	Unosumai-cho	M	70	1					1						Outside
3	Unosumai-cho	F	80	1	1										Outside
4	Unosumai-cho	F	60											1	Shelter
5	Unosumai-cho	F	60									1			Outside of Kamaishi
6	Unosumai-cho	F	50		1								1		Others
7	Unosumai-cho	F	60			1		1	1						Shelter
8	Unosumai-cho	F	50		1	1			1						Shelter
9	Unosumai-cho	M	70		1			1							Home
10	Unosumai-cho (E)	F	60		1								1		Relative/Neighbour's house
11	Unosumai-cho (E)	F	40											1	Shelter
12	Unosumai-cho (E)	M	70											1	Shelter
13	Unosumai-cho (E)	M	60		1	1			1						Shelter
14	Unosumai-cho	M	80	1		1									Shelter

15	Unosumai-cho	F	60	1				1							Home
16	Unosumai-cho	F	60					1					1		Home
17	Unosumai-cho	M	20												Relative/Neighbour's house
18	Unosumai-cho	M	80	1											Home
19	Unosumai-cho (E)	F	60	1						1					Relative/Neighbour's house
20	Unosumai-cho (E)	M	60	1											Outside
21	Unosumai-cho (E)	F	70											1	Shelter
22	Unosumai-cho (E)	F	30		1										Shelter
23	Unosumai-cho (E)	M	60									1			Relative/Neighbour's house
24	Unosumai-cho (E)	F	70	1	1										Relative/Neighbour's house
25	Unosumai-cho (E)	F	60	1		1			1						Relative/Neighbour's house
26	Unosumai-cho (E)	M	20		1										Relative/Neighbour's house
27	Unosumai-cho (E)	F	40					1	1						Relative/Neighbour's house
28	Unosumai-cho (E)	M	60							1	1				Shelter

29	Tenjin-cho (E)	F	80									1			Outside of Kamaishi
30	Tenjin-cho (E)	F	20							1					Relative/Neighbour's house
31	Tenjin-cho (E)	F	60		1	1									Shelter
32	Tenjin-cho (E)	F	70											1	Shelter
33	Tenjin-cho (E)	F	50	1								1			Relative/Neighbour's house
34	Tenjin-cho (E)	F	70		1										Relative/Neighbour's house
35	Tenjin-cho (E)	F	60											1	Shelter
36	Tenjin-cho (E)	F	80											1	Shelter
37	Tenjin-cho (E)	F	70										1		Shelter
38	Tenjin-cho (E)	F	80		1										Relative/Neighbour's house
39	Tenjin-cho (E)	F	70											1	Outside of Kamaishi
40	Tenjin-cho (E)	F	50	1	1	1									Shelter
41	Tenjin-cho (E)	F	80											1	Shelter
42	Tenjin-cho (E)	M	30	1					1						Shelter
43	Tenjin-cho (E)	M	80											1	Shelter
44	Tenjin-cho (E)	F	60							1					Shelter
45	Tenjin-cho (E)	F	30		1							1			Shelter
46	Tenjin-cho (E)	M	40											1	Others
47	Tenjin-cho (E)	M	70			1			1						Shelter

48	Tenjin-cho (E)	F	40			1		1							Others
49	Tenjin-cho (E)	F	60											1	Outside
50	Tenjin-cho (E)	F	40			1		1							Relative/Neighbour's house
51	Tenjin-cho (E)	F	-											1	Others
52	Tenjin-cho (E)	F	50											1	Shelter
53	Tenjin-cho (E)	F	80		1										Relative/Neighbour's house
54	Tenjin-cho (E)	M	70	1			1	1							Home
55	Tenjin-cho (E)	F	80											1	Shelter
56	Tenjin-cho (E)	F	60									1			Shelter
57	Tenjin-cho (E)	F	60											1	Shelter
58	Tenjin-cho (E)	M	60	1											Shelter
59	Tenjin-cho (E)	M	60											1	Shelter
60	Tenjin-cho (E)	F	80											1	Shelter
61	Tenjin-cho (E)	F	60	1				1							Relative/Neighbour's house
62	Tenjin-cho (E)	M	60	1	1										Home
63	Toni-cho	F	60		1				1						Relative/Neighbour's house
64	Toni-cho	F	70										1		Home
65	Toni-cho	M	80		1										Home
66	Toni-cho	F	80												Home
67	Toni-cho	F	60						1						Shelter
68	Toni-cho	F	60		1										Home

69	Toni-cho	F	60			1		1							Shelter
70	Toni-cho	F	70	1		1									Shelter
71	Toni-cho	F	10		1			1							Relative/Neighbour's house
72	Toni-cho	F	60	1					1						Relative/Neighbour's house
73	Toni-cho	M	60	1									1		Relative/Neighbour's house
74	Toni-cho	F	70	1				1							Home
75	Toni-cho	F	70	1			1	1							Home
76	Toni-cho	F	80		1										Home
77	Toni-cho	M	50						1						Relative/Neighbour's house
78	Toni-cho	M	40	1	1				1						Home
79	Toni-cho	M	40		1										Shelter
80	Toni-cho	M	50	1			1		1						Relative/Neighbour's house
81	Toni-cho (E)	F	40					1					1		Relative/Neighbour's house
82	Toni-cho (E)	F	70	1					1						Relative/Neighbour's house
83	Toni-cho (E)	M	60		1				1	1					Relative/Neighbour's house
84	Toni-cho (E)	F	70		1										-
85	Toni-cho (E)	M	40	1							1				Relative/Neighbour's house
86	Toni-cho (E)	F	50	1			1								Relative/Neighbour's house
87	Toni-cho (E)	F	50	1	1										Relative/Neighbour's house
88	Toni-cho (E)	F	70	1											Relative/Neighbour's house
89	Toni-cho (E)	M	50							1					Relative/Neighbour's house
90	Toni-cho (E)	F	50						1						Relative/Neighbour's house

91	Toni-cho (E)	F	50									1	1		Relative/Neighbour's house
92	Toni-cho (E)	F	70				1						1		Relative/Neighbour's house
93	Toni-cho (E)	M	30	1	1										Relative/Neighbour's house
94	Toni-cho (E)	M	50	1								1			Relative/Neighbour's house
95	Toni-cho (E)	M	60	1	1			1							Relative/Neighbour's house
96	Toni-cho (E)	F	70	1								1			Relative/Neighbour's house
97	Toni-cho (E)	F	60	1		1		1				1			Relative/Neighbour's house
	Unosumai-cho			9	10	5	0	6	6	2	1	2	3	4	
	Tenjin-cho			7	7	5	1	4	2	2	0	4	1	14	
	Toni-cho			17	12	3	4	7	9	2	1	4	5	0	
	Total			33	29	13	5	17	17	6	2	10	9	18	

Appendix C. Questionnaire for Semi-structured Interview with the Organizations

Interview Questionnaire (Yurtec Corporation, Kamaishi Branch Office)

Interview Date: 9th February, 2012

1. Causes and effects of the electricity outage in Kamaishi

(1) The coal-fire plant was shut. Was it because of the earthquake or electricity outage?
(2) For how many days did you have stock of fuel for emergency electricity generator? How many days did it take till additional light oil arrive?
(3) Is the generator (6MW) different from the emergency electricity generator for protecting facilities?
(4) What were the reasons it took 6 days until electricity supply was restored?
(5) What were other significant effects of electricity outage and fuel supply shortages?
(6) As I heard that Kamaishi Works supplied heating oil and heavy oil to a hospital in Kamaishi and water management office, did you have such a plan before the disaster or decided after it happened?
(7) Which hospital and water management office asked Kamaishi Works for oil supply? How much did they need?
(8) Based on the experience of the Great East Japan Earthquake, do you have a countermeasure plan for energy supply shortage for future natural disasters?

2. Opportunities and challenges in transition to ´decentralized supply system´ in Kamaishi

(1) I heard that Kamaishi Works sells electricity generated by the coal-thermal plant to Tohoku Electric Power Corporation. Assuming that the electricity market is more liberalized and generation is separated from transmission and distribution, do you have an idea to sell electricity to other organizations?
(2) What for do you use the heat from the power generation by the coal-thermal plant? Do you have an idea to use it for combined heat and power (CHP)?
(3) What is the mix rate of wood tip biomass in combusting coal for power generation?
(4) I heard that the mixing wood tip biomass with coal for power generation is conducted as a project funded by the Ministry of Economy, Industry and Trade (METI). What opportunities and challenges have you found from the project?
(5) Do you think that you can use such opportunities or address challenges by Kamaishi Works itself or by collaborating with stakeholders such as the municipality and the local forestry business community?
(6) Is it feasible to increase the mix rate technically and economically? Why?
(7) Do you also have business to sell wood tip biomass fir biomass stoves?
(8) What business opportunities do you see in ´Smart City´ project of Kamaishi City?

Interview Questionnaire (Yurtec Corporation, Kamaishi Branch Office)

Interview Date: 13th February, 2012

1. Causes and effects of the electricity outage in Kamaishi

(1) What are the causalities of electricity outage by the disaster?
(2) What was the restoration process of electricity supply in Kamaishi City? Why there were differences of speed of restoration amongst areas in Kamaishi?
(3) What countermeasures for electricity outage caused by natural disaster based on the lessons from the Great East Japan Earthquake?

2. Opportunities and challenges in transition to ´decentralized supply system´ in Kamaishi

(1) Which technological options are effective (in terms of technical and economic feasibility, and policies) to supply electricity for a while in case electricity outage occur by natural disaster?
(2) What opportunities and challenges are there in terms of stable electricity supply when introducing renewable energy technologies (e.g. wind, solar, wave)?
(3) What do you know about ´Smart City´ project of Kamaishi City? Do you see any business opportunities?

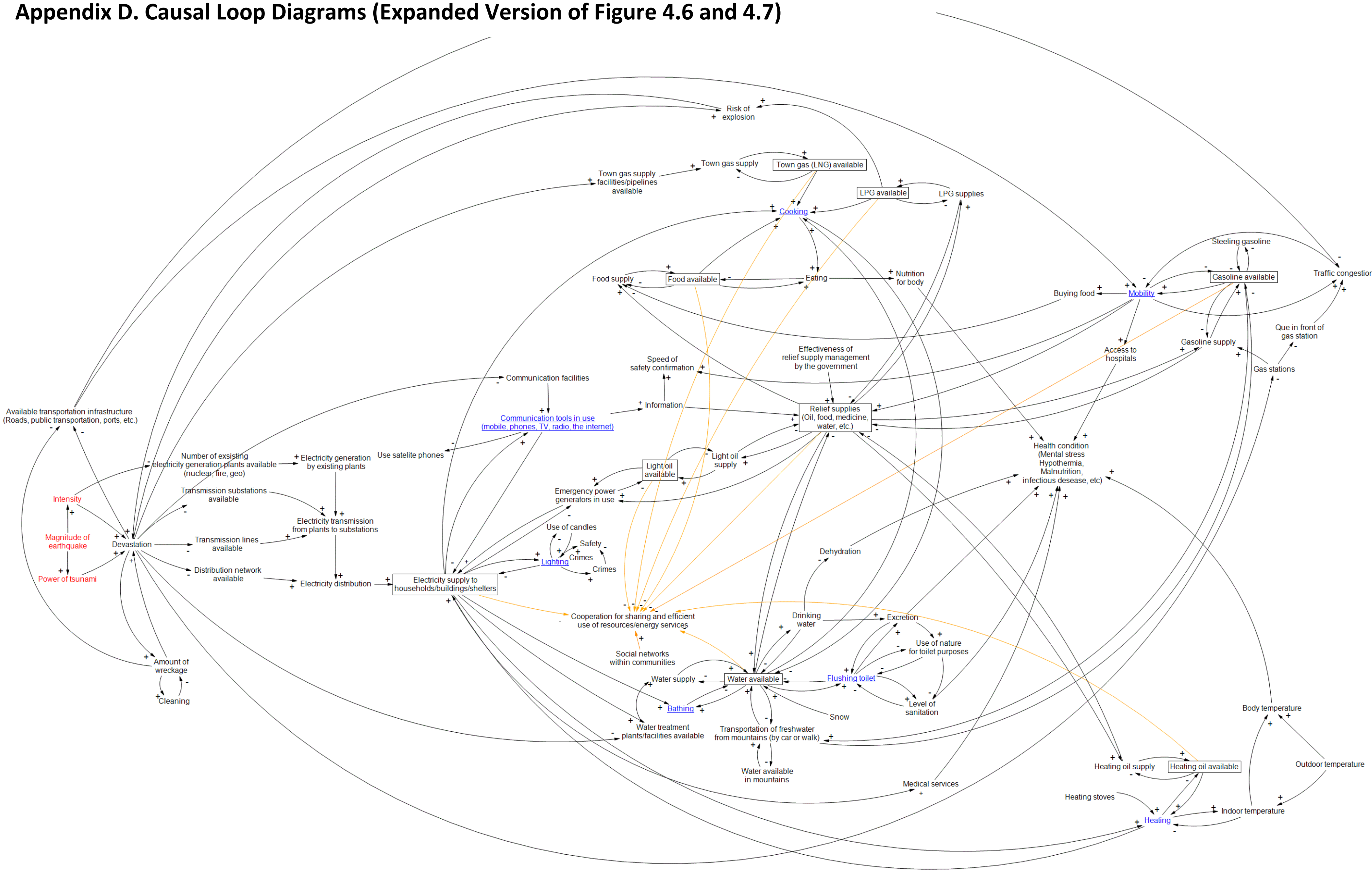
Interview Questionnaire (Rakuzankai Steel Memorial Hospital)

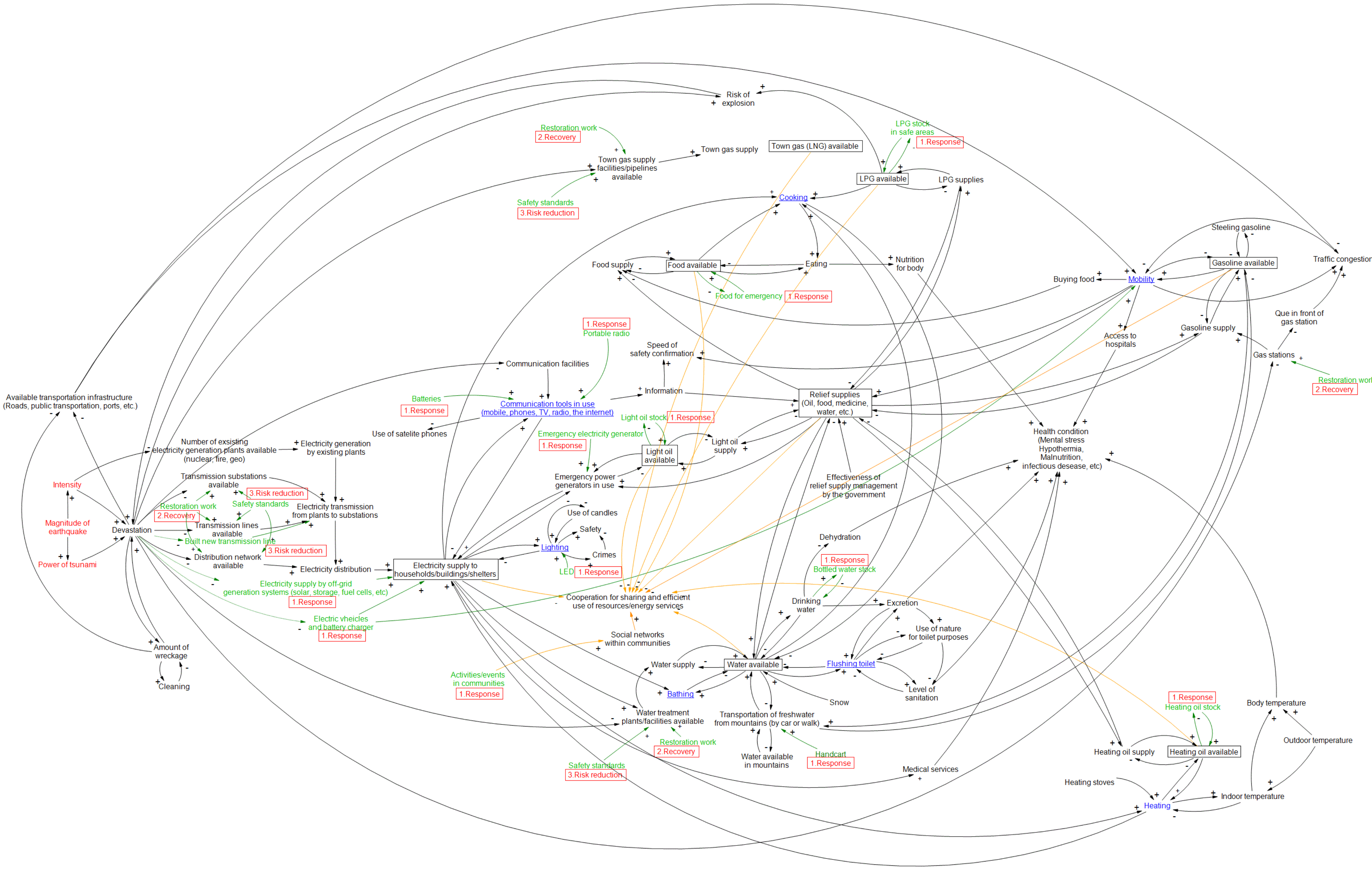
Interview Date: 15th February, 2012

1. Causes and effects of energy supply shortage on medical services in the hospital

(1) What energy sources were in need for medical services when energy supply was in shortage (including electricity outage)? What are the cases?
(2) What were the effects of lack of those energy sources on medical services?
(3) What measures did you take to minimize the effects of energy supply shortage?
(4) What countermeasures do you plan to prepare for energy supply shortage based on the experience of the Great East Japan Earthquake?

Appendix D. Causal Loop Diagrams (Expanded Version of Figure 4.6 and 4.7)




Risk of explosion
Restoration work
2.Recovery
Town gas supply
Town gas supply facilities/pipelines available
Town gas (LNG) available
LPG stock in safe areas
1.Response
LPG available
LPG supplies
Safety standards
3.Risk reduction
Cooking
Steeling gasoline
Traffic congestion
Gasoline available
Food supply
Food available
Eating
Nutrition for body
Buying food
Mobility
Food for emergency
1.Response
Que in front of gas station
Gasoline supply
Access to hospitals
1.Response
Portable radio
Speed of safety confirmation
Gas stations
Restoration work
2.Recovery
Communication facilities
Available transportation infrastructure (Roads, public transportation, ports, etc.)
Batteries
1.Response
Communication tools in use (mobile, phones, TV, radio, the internet)
Information
Relief supplies (Oil, food, medicine, water, etc.)
Light oil stock
1.Response
Use of satelite phones
Emergency electricity generator
1.Response
Light oil available
Light oil supply
Health condition (Mental stress Hypothermia, Malnutrition, infectious desease, etc)
Number of exsisting electricity generation plants available (nuclear, fire, geo)
Electricity generation by existing plants
Emergency power generators in use
Effectiveness of relief supply management by the government
Transmission substations available
3.Risk reduction
Intensity
Restoration work
2.Recovery
Safety standards
Electricity transmission from plants to substations
Use of candles
Magnitude of earthquake
Devastation
Transmission lines available
Safety
Built new transmission line
Dehydration
Distribution network available
3.Risk reduction
Lighting
Crimes
Power of tsunami
Electricity distribution
Electricity supply to households/buildings/shelters
LED
1.Response
1.Response
Bottled water stock
Electricity supply by off-grid generation systems (solar, storage, fuel cells, etc)
1.Response
Cooperation for sharing and efficient use of resources/energy services
Drinking water
Excretion
Electric vheicles and battery charger
1.Response
Social networks within communities
Use of nature for toilet purposes
Amount of wreckage
Cleaning
Water supply
Water available
Flushing toilet
Activities/events in communities
1.Response
Bathing
Snow
Level of sanitation
1.Response
Heating oil stock
Body temperature
Water treatment plants/facilities available
Transportation of freshwater from mountains (by car or walk)
Outdoor temperature
Restoration work
2.Recovery
Handcart
1.Response
Heating oil supply
Heating oil available
Safety standards
3.Risk reduction
Water available in mountains
Medical services
Heating stoves
Indoor temperature
Heating