A study on the effect of demand response to energy resilience of communities

(デマンド・レスポンスがコミュニティのエネルギー・レジリエンスに与える影響に関する研究)

周 允耀

A study on the effect of demand response to energy resilience of communities

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Declaration statement

I declare that this thesis entitled "*A study on the effect of demand response to energy resilience of communities*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....
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Date : September 2013

Abstract

The proposal of this study was to contribute ideas and solutions to ensure stable interaction among these three elements: human, architecture and energy. To be precise, the critical problems of interest in this study were about: exploring the underutilized potential of demand response program of a smart grid system, exhibiting the importance of considering the interests of both supply and demand sides when making any studies or practices related to energy system performance, and examining the concept of resilience and its applicability in the discussion of human, architecture and energy. Three research questions were formulated: What constitutes resilience? What in a community system are considered? How to assess energy resilience of a community system? As a way of investigating the aforementioned problems, this study aimed to propose an assessment methodology to study the effect of demand response capacity on energy resilience of communities based on bottom-up approach. The scope of this study was to demonstrate the usefulness of the proposed methodology to support decision-making process especially for energy suppliers, town planners and policymakers.

A series of intensive reviews of literature related to resilience and smart grid systems were made to assist in defining resilience and determining proper scope of assessment for this study context. Many existing literature describes resilience either as an ability to withstand disturbance, an ability to recover rapidly or an ability to adapt to changes but the definition of resilience has a different view. After reviewing more than 50 existing resilience definitions from various fields of study, analyzing them by identifying the fundamental structure of a resilience definition and the elements within the structure, and interpreting the meaning and representation of the identified elements, this study proposed that resilience is defined as the ability of a system depending on its own responsiveness and vulnerability to maintain its system functionality throughout any disturbances.

Literature reviews of resilience and smart grid systems supported the scoping of assessment target to be town-level community system including its power generation, network and consumption components. Town-level community was selected because it has the optimum size to function as a microgrid which is an essential factor in the study of resilience of power grid systems. The assessment data was decided to be based on daily power operation of a community system. Based on the proposed resilience definition, energy resilience of a community system is defined as the ability of a community system depending on its own responsiveness and vulnerability to maintain

its energy-dependent functionality throughout any disturbances. Disturbances in this study was defined as any destabilizing factors that can cause small-scale and short-term difficulties to daily power operation of a community system to achieve power balance. In addition, this study assessed a system based on its performance to stay resilient and did not look into the system performance in unresilient state. Therefore, the recovery rapidity of a system was not considered in the assessment.

There were two categories of indicators used to assess energy resilience: functionality and attribute indicators. Functionality indicators were used to represent resilience performance of a community system and were assessed based on overall system functionalities. System functionalities that are significant from the perspective of both supply and demand sides were selected as functionality indicators: power balance of daily power operation was selected to represent the functionality indicator for the supply-side interest where as demand users' convenience and cost of electric energy were for the demand-side interests. Attributes indicators represented significant supporting performance that must be taken into consideration and were assessed based on the performances of power generation, network and consumption components of a community system. Redundancy, adaptability, reliability and vulnerability were chosen as the attribute indicators because they are among the top attributes most representative of resilience. In addition, the interdependency among the proposed indicators and how key stakeholders can influence on the performance of the proposed indicators were explained.

An analysis model was formulated to model a community system and its power components to simulate daily power operation of the community. The analysis result was used as the input for assessment model. Essentially, the modeling of a town-level community was based on bottom-up approach that modeling began from building level, then aggregating through neighborhood and village levels in between to finally arrive at the community level. The bottom-up approach was applied to model power supply, demand and demand response capacity. Community power demand is the total of power demand of different building types. Power demand of a building type was modeled by first summing up all of its unit demands per building floor area (BFA) for different energy uses such as heating, cooling, hot-water making and electric appliances and then multiplying it with the BFA of the building type. Regarding on the modeling of demand response capacity, as there was no available and reliable statistical information regarding the demand response potential of each building type, the best effort in this study was to estimate it as the percentage of ongoing power demand which can be turned off. This estimation approach was very similar to modeling power demand that demand response potential was estimated beginning from the unit demands per BFA for energy uses such as heating, cooling, hot-water making and electric appliances and then added up together to form the total demand response potential of the building type. Simulation of daily power operation was made by using the developed models and the power flow analysis was used as a means to verify the feasibility of each simulated result. Verifying and validating the analysis model are to a limited extent equal to verifying and validating the assessment model itself. While verification could be made, the validation of the assessment model was not feasible at the time of this study was made because the required information was not available or disclosed.

For the purpose of studying the effect of demand response to energy resilience of community systems under various disturbance conditions and demonstrating the usefulness of the proposed methodology in supporting decision-making process, a case study was made by using the developed analysis model. Three towns with different characteristics in the aspect of town composition were used. The town highly composed by residential building was represented by Umegaoka town in Setagaya district, the town highly composed of high-rise residential, office and commercial buildings was represented by Toyosu town in Koutou district and the town highly composed with residential buildings and consisted of a substantial percentage of small factories was represented by Kitakoujiya town in Oota district.

Four disturbance cases were prepared to simulate four different disturbance situations when decisions needed to be made. These disturbance cases were composed by 13 disturbance scenarios which represented the reduction of generation capacity of the bulk power supply and service deterioration of some power components. In each disturbance scenario, the community system of every case study was modeled with five levels of demand response capacity to examine how different levels of demand response capacity can contribute to and affect energy resilience. The preparation of the five levels of demand response capacity was based on extreme conditions that the analysis adopted the *possible* designs, instead of *representative* configuration of demand response capacity of a community. In addition, optimization of case studies was also made to demonstrate the applicability of the proposed methodology to assist in optimization of energy resilience of communities. According to the analysis and assessment results, Kitakoujiya town was the most resilient town among the three towns because it could achieve energy resilience in most disturbance scenarios whereas the other two towns were unresilient. Through discussing the result of each disturbance case, the usefulness and implications of the proposed methodology to decision makers such as energy suppliers, town planners and policymakers were explained.

The conclusion of this study examined the extent of the objectives of this study have been achieved. This study proposed an assessment methodology, the proposed assessment methodology was used in a case-study analysis to study the effect of demand response capacity on energy resilience of communities and demonstrate the usefulness (and limitations) of the proposed methodology in decision-making process. Also, the analysis results conditionally supported the first generated hypothesis that a community with more demand response capacity is more resilient because DR capacity can be used as virtual power supply source to achieve power balance. This study could not support the second generated hypothesis that a community composed more uniformly by various building types is more resilient. It is important to note that the analysis was just a means to demonstrate the application of the proposed methodology, the results of the analysis and assessment from the case study are not supposed and cannot be used to establish any statistically significant relationships between demand response capacity and energy resilience.

Acknowledgement

Three years working on this doctoral thesis, two years for my master's thesis and half a year of preparatory period as a research student, it has been 5.5 years for me to pursue my graduate studies in the Yashiro Laboratory of the University of Tokyo in Japan. In this half a decade, I have been learning from and given several opportunities and constructive advices by Professor Yashiro, not only in academy but also in real-world practice such as collaboration research works with industry practitioners. Besides that, I also sincerely appreciate his extensive concerns and supports on students' living situations and future prospects.

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To my beloved family…

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Chapter 1

Introduction

This study attempts to create and improve resilience of a community in the aspect of energy performance. This first chapter mainly explains the problems this study aims to provide solution proposal for, the methodology used to achieve the research aim and the significance of this study in helping to solve the target problems. Besides that, the scope and originality of this study are explained as well.

1.1 Background

One third or so of the total energy consumption of many countries such as Japan and the United States, are consumed by building sectors. Energy consumed by building sector is usually consumed in the form of electric energy. Energy is consumed within any architectures such as the offices, factories or houses to support all kinds of human activities. Productivity and comfort of human are also highly dependent on energy supply, for example, to provide lighting in dark spaces and heating or cooling during winter or summer. Energy is an indispensable commodity but it also comes with plenty of problems and issues, for example, the depletion of energy sources, power outages and the pollution caused by the energy production. The implementation of smart grid has been known as a latest attempt to solve various energy-related problems. The concept of a smart grid advocates the use of renewable energy and demand-side management that the energy generation has started to shift from centralized generation to distributed generation, and demand-side users are expected to participate in daily operation of electric energy supply and demand more often than ever. However, new solutions come together with new issues. For example, most of the renewable energy such as solar and wind power generation have difficulty in providing a reliable energy supply because they rely on the weather conditions, and demand-side management such as demand response (DR) program extended to low-level demand users (residents, etc.) is still relatively new and requires proper study so that the implementation can make full use of its potential.

Research and development in many areas are needed to ensure that a smart grid is designed, implemented and operated in the correct way. Researches about smart grid such as the smart meter (Joung & Kim, 2012), photovoltaic and wind generation, electric vehicles and combined heat and power devices, to scale as large as studying the whole power grid system such as studying the effect of distributed generation on the power quality (Hamedi & Gandomkar, 2011) (Khadem, et al., 2010) (Yang & Chen, 2011) (Li, et al., 2010), and optimization through interconnecting power grids across a number of countries (Rombauts, et al., 2011) (Watcharejyothin & Shrestha, 2009). Apart from the technical researches that concern on the power grid system components like the generation, transmission, distribution and consumption system, other important non-technical researches of smart grid include the DR management (Torriti, 2012) (Rastegar, et al., 2012), users' comfort, energy policy, electricity market (Milstein & Tishler, 2011) (Finn, et al., 2011) (Joung & Kim, 2012) and so on. There are also many researches about modeling, simulation, optimization and assessment regarding the technical and non-technical issues of smart grid. However, it has been a growing issue that most of these research-and-development works are usually done in ad hoc or one-sided manner that the supply side and demand side of a power system are carrying out their studies focusing on their own interests only. For example, due to data availability, the design or planning of power generation from the supply-side power utility companies are usually optimized to minimum the production cost without considering much about the interest of the users from the demand side, and on the other hand, many facility managers of office buildings or factories from the demand side usually optimize the building operation to achieve energy efficiency without considering much about the interest of the supply side. These conditions limit the optimization to local-level only. As users from the demand side are able and expected to participate in the operation of a smart grid through generating power locally and responding to grid operator to change their consumption behaviors, a design, planning or operation of a smart grid which is optimized by considering interests of both sides are necessary, not only to achieve better energy efficiency or economic benefits, but also to make sure that both sides are satisfied and compromises are minimum.

Besides the insufficient collaboration between the supply and demand sides, both sides have been receiving challenges and impacts from many internal and external disturbances in maintaining daily balancing operation of power generation and consumption. Disturbances of various severity have caused problems to the interaction of energy, architecture and energy (*Figure 1*). For example, in some countries such as the United States, its national power grid has been known to be vulnerable to failure and overloading and it has been experiencing a lot large power outages in recent years, such as Northeast Blackout of 1965 and 2003, the blackout in the west part in the July of 1996, and Los Angeles Blackout of September of 2005. While in some countries famed for their robust national power grids such as the Japan, the trouble of its power grid has been caused by external factors like the earthquake and tsunami in Tohoku, year 2011, and internal factors such as the stability issue of having large amount of fluctuating distributed generation (solar, wind power and etc.). The human or the users need to perform various activities to support their lives, the building architecture becomes the place where most of the human activities take place and the energy especially the electric power is the source of force supporting and facilitating those activities. Therefore, a lot of researches are needed to ensure stable interaction among these three elements: human, architecture and energy.

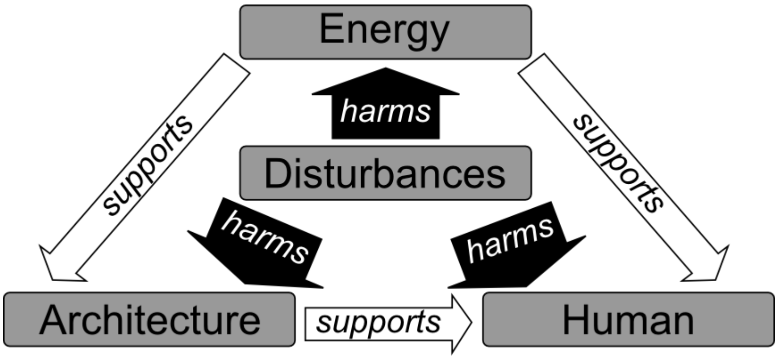


Figure 1 Disturbances harm interaction of energy, architecture and human.

This study attempts to address the issue of making the power grids or the smart grids even more robust to disturbances so that the demand users can maintain being productive and comfort in their activities such as daily life activities or works, and the buildings can maintain their functions to provide a safe, comfortable and healthy environment to the building users. Resilience is defined as the ability to recover quickly from difficulties, according to Oxford Dictionaries. The interest of this study is not limited to making the power grid system robust or reliable, but also resilient, which is the ability to recover back to the state so that it can perform its assigned functions. This study attempts to help to create resilient electric energy supply to the demand-side users in any situation including the time when disturbances occur.

There are many possible ways to do it. ***This study attempts to address this problem through proposing a methodology to assess resilience of a community in the aspect of energy performance.*** There are many factors affecting resilience performance, this study concentrates on DR.

1.2 Problem statements

This study will explore the underutilized potential of DR program of a smart grid system, exhibit the importance of considering the global performance and interests of both supply and demand sides when making any studies or practices related to energy system performance, and examine the concept of resilience and its applicability in the aspect of human activities, architecture robustness and energy security. These research problems have been formulated into research questions in the next section.

1.2.1 Research questions

It is necessary to establish a connection between a community and resilience (*Figure 2*). Basically, three main research questions need to be answered in order to assess the effect of DR on energy resilience of a community.

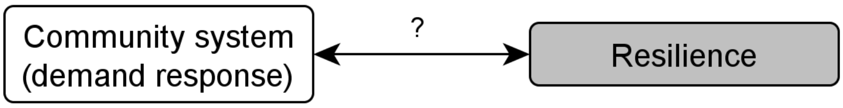


Figure 2 A need to establish connection between a community system and resilience for assessment

What constitutes resilience?

There are many existing definitions available from different disciplines of study. Most of them consider resilience as an ability of a system to remain stable and functional, and to recover back to its stable and functional state if it has failed. In this study, the author proposes an alternative resilience definition and argues that resilience of a system can be measured by the achievement of the system functionalities and other supporting performances.

What in a community system are considered?

The focus is to study the effect of DR capacity on energy resilience of communities but there are also other significant factors that must be taken into consideration. In this study, DR capacity is defined as the power demand that users will *potentially* reduce when requested by the power utility company. A system consists of many components and in the case of a community system, it also has power generation and network components besides the power consumption components. Good functionality performance of a community system is the result of good interdependency among those components. Therefore, power capacity from generation components and power flow capacity from network components are also considered in this study.

How to assess energy resilience of a community system?

An assessment methodology and a set of indicators are proposed based on the answers from the first two research questions: the resilience definition and the power components considered in the power operation of communities. An assessment model is then developed and case study is made to demonstrate the effect of DR capacity on energy resilience of communities. Results and findings of case study, usefulness and limitations of the proposed assessment methodology and indicators and their implications and applicability to the practical world are discussed.

1.3 Research aim

In responding to the problem statements, ***this study aims to propose an assessment methodology to study the effect of demand response (DR) capacity to energy resilience of communities based on bottom-up approach***. The assessment methodology should have the following characteristics:

- To support, guide and facilitate the main target users such as energy suppliers, town planners and policymakers in the process of decision making.
- To assess energy resilience based on global performance covering supply and demand sides rather than just local or one-sided performance.
- To be understandable to professional and non-professional audience.

The assessment subject is a community system including all the relevant energy systems connecting to the community from within or outside. The bottom-level components of the community system consists of power generation, network and consumption components. The collective assessment results represent the system resilience of the community. The assessment data is based on daily power operation and operation condition of the power system components.

1.3.1 Research objectives

In order to answer the research questions strategically, the research aim is split into five interdependent research objectives (*Figure 3*) as shown below.

i) To define resilience for this study context through extensive literature reviews.
ii) To propose an assessment methodology of resilience based on definition from (i).
iii) To develop a bottom-up assessment model of energy resilience of communities based on methodology from (ii) together with the proposal of assessment indicators.

iv) To apply the assessment model from (iii) in case study to study how energy resilience of a community is affected by DR capacity.

v) To demonstrate the usefulness and implications of the proposed methodology to the real world through the discussion of the results of case study, and to discuss the limitations of this study.

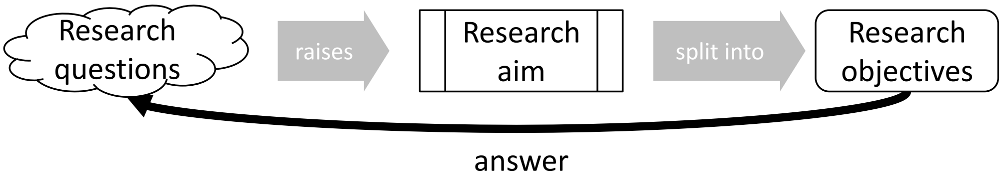


Figure 3 Achieving research objectives to answer research questions

1.3.2 Research outputs

The expected outputs come from this study are listed below.

- A resilience definition come from the author's own comprehension after extensive literature review.
- A bottom-up assessment methodology which can be used and adopted to make models to assess resilience of community systems.
- Findings about the general relationship between energy resilience of a community and DR capacity and discussion of the implication and applicability of the proposed assessment methodology to the real world especially in supporting decision making.

1.4 Scope of research

An assessment methodology will be proposed in this study. As this resilience study is still new in the field of architecture and Japanese power industry, this study is limited to demonstrate the usefulness and implications of the proposed methodology to support its users in the process of decision making through simulation-based case study, however, it is not the scope of this study to verify or validate the usefulness of the proposed methodology and the analysis and assessment results.

Some other important scopes of this study are listed below:

- This study follows a new resilience definition proposed in this study which assesses resilience based on functionality performance rather than resistance capacity and recovery rapidity of a system. Nonetheless, this study assesses a system based on its performance to stay resilient and does not look into the system performance in unresilient state. Therefore, the recovery rapidity of a system is not considered in the assessment.

- While this study does not specify any limit to the kind of disturbances that can happen to a community system, however, the effects and damages caused by the disturbances to system performance are limited to those that are small-scale and short-term. Large-scale and long-term effects or damages to system performance are not the target of this study because assessment considering recovery will become significant.
- In general, only power generation and consumption of buildings (houses, offices, factories, hotel, etc. including their distributed generation) taking place within a community and from the supply side are considered.
- The target scale of community is set at town-level community (Please refer to *4.1.3 Scale and system boundary of assessment*).
- The working concept of DR program applied in the study is that the power utility company treats the users' power demand as a virtual source of power supply instead of trying to form desired demand patterns from the demand side.
- The modeling of the distribution network system in a community is simplified so that only power capacity is considered. The fluctuation of power voltage and frequency is assumed to be under the control by other power equipment such as capacitors and regulators.

Other relevant scopes, assumptions or limitations of this study will be explained in the following sections where relevant.

1.5 Research methodology

Regarding research methodology, this study can be considered to consist of four parts: review, methodology proposal, data collection and analysis. The research methodology used in each part of the research is summarized in *Table 1*.

Table 1 Research methodology applied in each part of research

Methodology / Part	Review	Proposed methodology	Data collection	Analysis
Primary sources				
Journals, conference papers, reports, website articles, etc.	✓	✓	✓	✓
Hearing and opinions of experts from relevant academy and industries	✓	✓	✓	✓
Personal correspondence through the internet				✓
Raw and measured data			✓	✓
Published statistical data			✓	✓
Secondary sources				
Books, reports, website articles, etc.	✓	✓	✓	
Computational modeling and simulation				✓

1.6 Research philosophy

A research philosophy is a belief about how a researcher defines a problem, collects data and information, and analyzes the problem. According to the categorization done by Sinclair (Please refer to *Appendix 1*, page *156*), the epistemological stance of this study is positioned to be *modified objectivist* which falls under the category of post positivism. Under this post positivism, this study is more inclined to the positivism rather than the interpretivism (or anti-positivism), because the author strived for objectivity throughout the research process so that the reproduction of the result is possible. The author has tried to avoid interfering the research process with any bias or subjective judgment where possible, however, some parts of this study still contain the element of subjectivity, especially in where assumptions need to be made.

1.6.1 Concept used for systems thinking

This study aims to assess energy resilience of communities. A community is viewed as a system consisting of many components. There are two concepts when explaining a system: reductionism and holism. Reductionism asserts that a complex system can be explained by breaking it down to its fundamental parts. On the contrary, holism claims that the whole can be more than the sum of its parts and therefore a system is not supposed to be analyzed through its smaller parts. The arguments and debates between the two concepts have been around in the academic fields and therefore will not be discussed here.

In this study, the author practices the concept of reductionism. According to the author's belief, a system is equal to the sum of its parts and vice versa, and the limited knowledge and ability of human to explain everything are the reasons why inequality occurs between the system and the sum of its parts.

1.6.2 Theory applied in assessment

Among all the relevant theories or concepts such as sustainability, robustness, reliability and so on, the theory of resilience has been chosen in this study. A simple definition of resilience is the ability to recover quickly from difficulties (Oxford Dictionaries, n.d.). This theory of resilience is considered to be suitable for this study to study the ability of a community to support the activities of its members in any situation including when disturbances happen. Further explanation about what resilience is and how resilience is different than other theories and concepts are explained in *2.3 Resilience* and *3.3.1 Distinguishing resilience*.

1.7 Hypothesis generation

Case study is carried out by using the developed assessment model to better understand the effect of DR capacity on energy resilience of communities. This kind of study is relatively new and at its early stage and therefore instead of testing hypotheses, this exploratory study attempts to generate hypotheses (Fixson, 2002, p. 145). The hypotheses generated for this study are listed as below.

- A community with more DR capacity is more resilient.
- A community composed more uniformly by various building types is more resilient.

1.8 Originality and significance of research

An important originality of this study is the application of the resilience concept into investigating the problems of energy, architecture and human. The number of studies related to resilience, reconstruction, regeneration and others has started to increase recently, which is believed to be related to the increasing occurrences of disasters around the world. The resilience study is considerably new in the field of architecture and power industry in Japan and this study explores a novel study area by looking into how energy resilience of communities is affected by DR capacity. This study also plays the role of an exploratory and pioneering work in this topic to stimulate more similar studies and discussion in the future.

The proposed assessment methodology is original and can be used to facilitate decision making among key stakeholders in order to create a win-win situation for both supply and demand sides. For example, based on the assessment result, energy suppliers can design more efficient DR programs and develop strategic power operation plan, policymakers can create proper policies to influence community members in the participation in DR program or investment of distributed generation such as solar generation. The same goes to city planners or urban planners too when developing a community or city. In addition, the consideration of the global performance and the interests of both supply and demand sides when assessing the energy resilience of communities is significant to encourage similar consideration in real-world practice.

When in real life power utility companies around the world tend to promote time-based DR program which is a supply-side means to affect demand-side power consumption to follow supply-side desired pattern, this study adopts the working principle of incentive-based DR program in which users' power demand is considered as a virtual source of power supply. This decision is made with the intention to contribute to more studies about how DR capacity under the working principle of incentive-based scheme can help in creating more resilient performance of a community or a power grid system. It also can be used for comparison materials for other studies.

1.9 Research framework

Research framework of this study is illustrated in *Figure 4*. This study begins with reviews of theories, working principles and conceptual ideas, and also real-world examples of resilience, smart grid and DR from available literature materials or accessible primary sources. The outputs from the reviews are used to propose a methodology to assess the effect of DR capacity on energy resilience of communities. In order to demonstrate the usability and applicability of the proposed methodology, an assessment model is developed. The development of the assessment model involves the process of proposing resilience definition and indicators and also deciding the modeling and simulation methods to be used in analysis. After that, case studies are designed and prepared by selecting and referring to real-world towns. Simulation analysis is made to the town-level communities by using the developed analysis model and then the energy resilience of those communities are assessed with the developed assessment model. The results of analysis and assessment from the case studies are then interpreted to present the usefulness and limitations of the proposed assessment methodology and indicators. Useful findings and insights from the analysis results, and implications and applicability of the proposed methodology and indicators to real-world development of resilient communities are discussed. In the end, conclusion and recommendation of future studies for this research topic are provided.

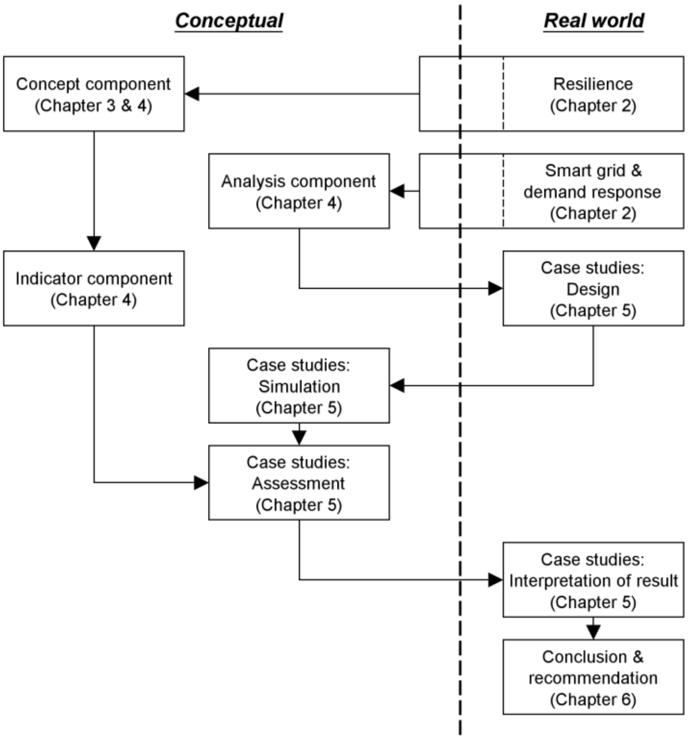


Figure 4 Research framework

1.10 Thesis structure

This thesis consists of six chapters. The first chapter is the introduction of the research problem, research aim and research methodology. The second chapter is the literature review of the key subjects related to this study, namely the resilience and smart grid systems. The third and fourth chapters are each about the proposal of the assessment methodology and the development of the assessment model. In the fifth chapter, explanation of case-study analysis using the assessment model and discussion of the analysis results and usefulness of the proposed methodology are reported. The final chapter concludes this study and recommends future studies of this research topic.

Chapter 2
Literature review

Before going into the original research works by the author, this chapter aims to provide quick introduction and state of the art of the key subjects related to this study. The key subjects are smart grid, disturbances to power grid system and resilience. All the important information influenced the author, used or referred by the author in this study are included.

2.1 Smart grid

Conventionally, electric energy or electric power is delivered from the supply side to the demand side through a power grid system. As shown in *Figure 5*, a power grid system generally consists of generation, transmission and distribution systems. The electric power usually flows from the supply-side generation system, through the transmission and distribution network systems, to the demand-side consumption points. For different countries, the problems they have with their power grid systems are exclusive due to different development backgrounds and other factors (*Table 2*). Many countries are now upgrading their power grid systems to become smart grid systems in order to solve their exclusive problems.

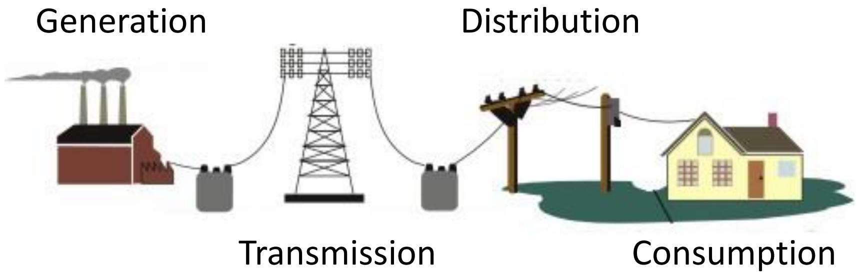


Figure 5 Power grid system

Table 2 Problems faced by power grid systems of different countries [山藤, 2010] (Friedman, 2009)

Country	Problems of power grid system
Unites States	Vulnerable, overloaded, system bottleneck, integration of renewable energy, reliability, power quality
Europe	Fluctuation of high adoption of renewable energy
Japan	Fluctuation of high adoption of renewable energy, weakness against disaster
China	Growing demand and new system

A smart grid is a solution to the problematic power grid system of each country and plenty of researches and articles have discussed about it (Hamilton, et al., 2010) (International Energy Agency (IEA), 2011) (Friedman, 2009). As defined by the European Regulators' Group for Electricity and Gas (ERGEG), a smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, customers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies (European Regulators Group for Electricity & Gas (ERGEG), 2009). The International Energy Agency (IEA) defines a smart grid as an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability. As each country has different background and problems, a smart grid means different things to different countries and people. Crossley defines that a smart grid, at a simplistic level, is a method of delivering electricity from suppliers to consumers using information technology and communication systems. An intelligent communications system between suppliers, consumers, storage systems, and the components of the electricity grid would save energy, reduce cost and maximize the use of national, local and domestic sources of low carbon energy (Crossley & Beviz, 2010).

Among many different definitions, most of them have similar interpretation about the features and characteristics a smart grid should have and the problems it should be able to solve or help. A smart grid advocates more development and implementation of distributed generation and demand-side management to work together with centralized generation and supply-side management to achieve its objectives. In a smart grid system, the electric power and information flow between supply side and demand side shift from one-way to two-way, and the demand-side users have more control and are expected to participate and be more involved than ever in the operation of power grid system (*Figure 6*). By solving and reducing problems such as peak demand, blackouts, and carbon emission, smart grid system can support various human activities in comfortable environment.

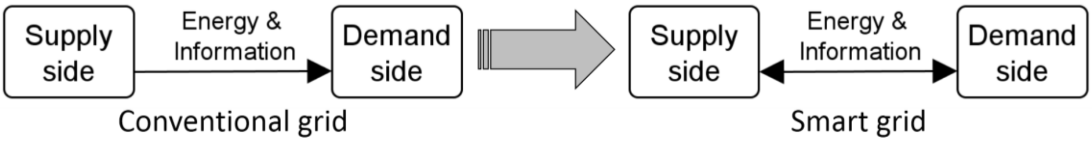


Figure 6 Shift from one-way to two-way flow of information and electric power between supply side and demand side in a smart grid system

2.1.1 Daily power operation

A smart grid system and a conventional power grid system do not vary much in their daily operation in supplying power to meet the demand through a series of operations as shown in *Figure 7*. Electric power cannot be stored easily and cheaply and is ideal to be consumed when it is generated. Therefore, the supply side forecasts the demand of the next day in order to prepare generation scheduling plan that is reliable and economic. Regarding forecasting for demand baseline, many methods are available, from simple to complicated ones. *Table 3* shows the comparison of a few forecasting methods. Based on the forecasted demand (or demand baseline), and also the working and availability status of generators and other system components, the supply-side system operator prepares a generation scheduling plan to meet the forecasted demand. Conventionally, the generation scheduling is optimized according to production cost and also other requirements such as carbon emission.

Figure 7 A series of operations in a daily power operation

Table 3 Comparison of baseline methodologies (Association of Edision Illuminating Companies (AEIC), 2009)

Baseline Methodology	Pro	Con
Previous Day	• Most likely the same usage pattern as the event day • Easy method for customer to understand	• Does not take into account the effects of weather on load • The need for a baseline adjustment
Average Daily Usage	• Easy method for customer to understand • Averaging takes out the variability in load for the days used to create the average day	• An average load shape created from multiple day load shapes will not totally capture the usage pattern for an event day • The need for a baseline adjustment
Proxy Day	• Matches a day based on defined variables uniform with event day	• Finding a day based on the defined variables • The need for a baseline adjustment • There might not be a day to use as the proxy day
Regression Model	• Concept of variable relationship is easy to understand	• Customer understanding of the process used • Selecting the correct variables to use in this model

There are many possible disturbances to the operation of a power grid system (Please refer to *2.2 Disturbances to power grid systems*, page *32*). In daily operation of power supply and demand, disturbances such as forecast error and sudden breakdown of generators result in power imbalance between supply and demand. For the purpose of balancing the supply and demand, ancillary services are needed (Please refer to *2.1.3 Ancillary services and operating* reserve, page *18*). Again, the ancillary services are optimized usually based on the supply-side interests, such as the cost of operating reserve. During the daily operation, any disturbances are possible to cause blackout and then restoration will start to recover the affected areas (Please refer to *2.2.1 Blackout and restoration*, page *36*).

2.1.2 Power balance

It is important to maintain power balance for both supply and demand sides. Large power imbalance can cause substantial fluctuation of power frequency and voltage and if this situation remains for a long time the equipment of the supply or demand sides is likely to be damaged or fail. A conventional way of balancing is the dispatching of operating reserve and if that still cannot bring back the power balance, the last resort is to shut down the power supply to some areas. In the case of the demand users have installed enough distributed generators such as on-site generators, solar and wind power generators or energy storage such as battery storage, the affected area can generate and provide power to supply for themselves. This situation is known as microgrid which is a feature to be realized through smart grid systems.

Power balance experiences a problem when the demand is greater than the supply, especially during the time of peak demand (day time), and that will cause power frequency and voltage to decrease. On the contrary, when the demand is less than the supply in the night time, the power frequency and voltage will increase. Both cases of power imbalance remain as a problem to the normal operation but somehow the case of oversupply is relatively easier to deal with (Rebours & Kirschen, 2005, p. 9). New features of smart grid systems especially the distribution generation and demand-side management have the potential in facilitating the power balance (Please refer to *2.1.6 Generation portfolio* and *2.1.4 Demand side management*).

2.1.2.1 Community as a solution

The idea of relying on on-site power supply and storage to meet the demand is known as the microgrid. A microgrid is a solution to demand-side users who experience problems in getting reliable and provision of power supply, especially people living in islands or isolated areas. Besides meeting the power demand with physical and hard solutions such as distributed generations, managerial or soft solutions have been studied to complement to the former type of solutions. For example, a group of buildings with different demand patterns can be linked together to form a community and share a community-based energy system. By carefully managing the selection of community members (buildings with different demand patterns) to be linked together as a community, the community-based energy system can be optimized in the aspects of performance and cost (Chew, 2010).

2.1.3 Ancillary services and operating reserve

Ancillary services of a power grid system can be defined as those services required to ensure that the interconnected electric system is operated in a manner that provides a satisfactory level of service with acceptable levels of voltage and frequency (Alberta Electric System Operator (AESO), n.d., p. 7). AESO also defines operating reserve as available output from a generator that can be dispatched, or load that can be reduced, to maintain system reliability in the event of an imbalance between supply and demand on the electricity system. There are different kinds of operating reserves to provide ancillary services for different situations or disturbances. *Figure 8* shows how operating reserve is categorized and *Figure 19* (Please refer to *2.2 Disturbances to power grid systems*, page *35*) shows the categorization of dynamic phenomena or disturbances of power grid systems by time characteristics of the disturbances. Further details such as dispatchability of each type of operating reserve is explained in *Table 4*. In addition, *Figure 9* shows the response time and duration of operating reserves and the type of ancillary services covered each of them.

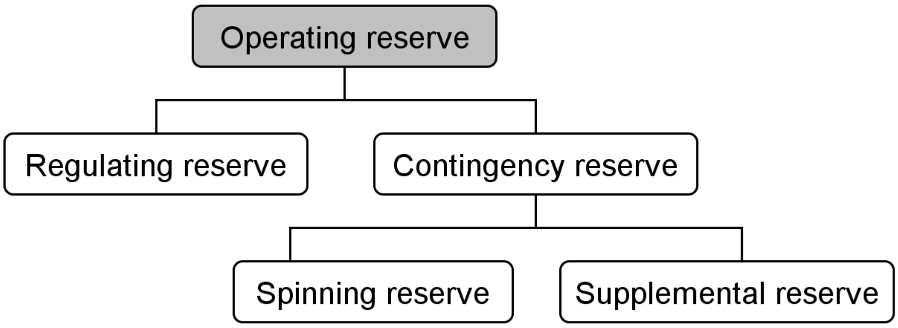
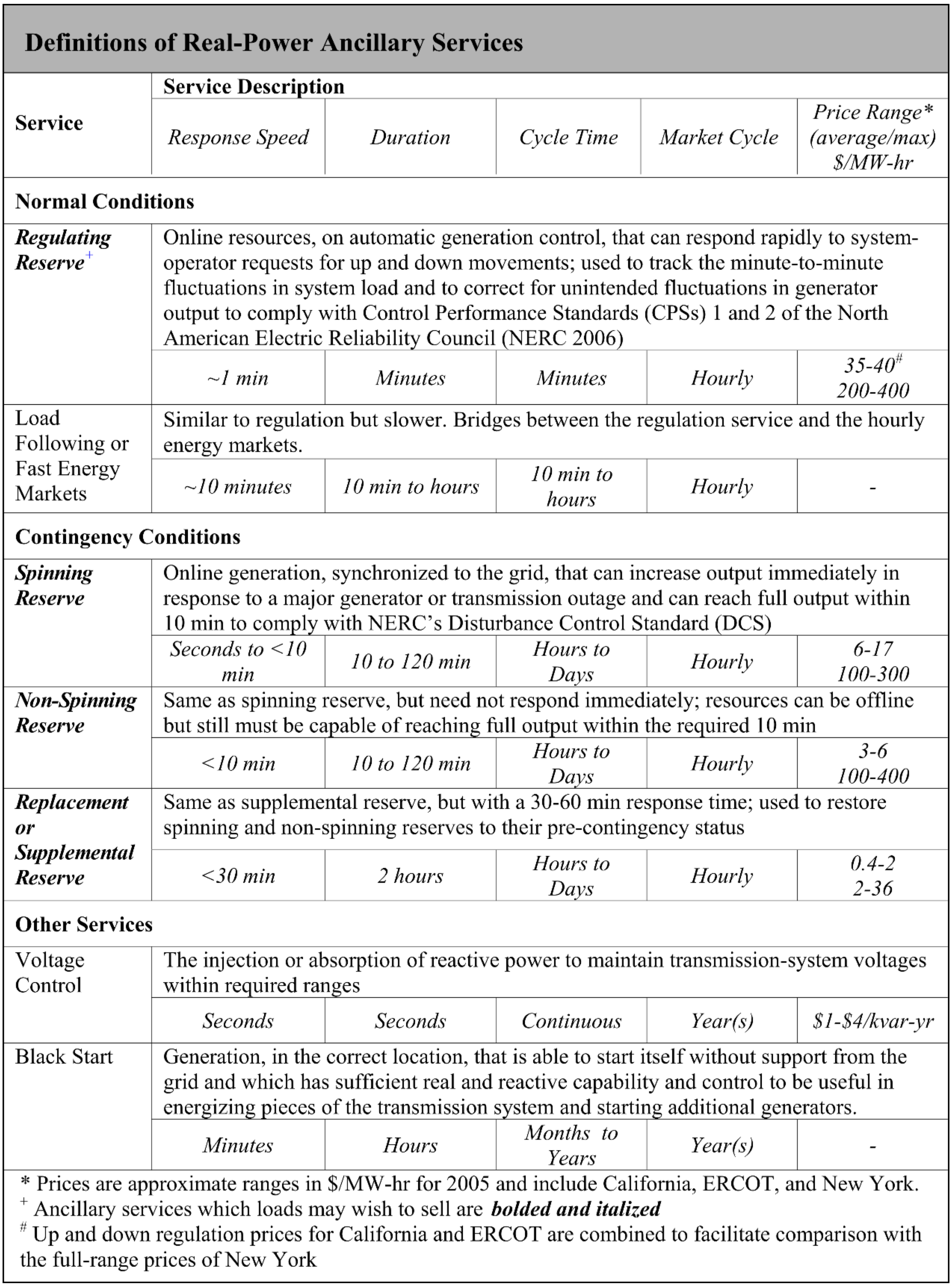


Figure 8 Categorization of operating reserve

Table 4 Definitions and characteristics of various operating reserves (Kirby, 2006)



Definitions of Real-Power Ancillary Services

Service	Service Description				
	Response Speed	*Duration*	*Cycle Time*	*Market Cycle*	*Price Range** *(average/max)* *\$/MW-hr*
Normal Conditions					
Regulating Reserve^{+}	Online resources, on automatic generation control, that can respond rapidly to system-operator requests for up and down movements; used to track the minute-to-minute fluctuations in system load and to correct for unintended fluctuations in generator output to comply with Control Performance Standards (CPSs) 1 and 2 of the North American Electric Reliability Council (NERC 2006)				
	~1 min	*Minutes*	*Minutes*	*Hourly*	*35-40*$^{\#}$ *200-400*
Load Following or Fast Energy Markets	Similar to regulation but slower. Bridges between the regulation service and the hourly energy markets.				
	~10 minutes	*10 min to hours*	*10 min to hours*	*Hourly*	-
Contingency Conditions					
Spinning Reserve	Online generation, synchronized to the grid, that can increase output immediately in response to a major generator or transmission outage and can reach full output within 10 min to comply with NERC's Disturbance Control Standard (DCS)				
	Seconds to <10 min	*10 to 120 min*	*Hours to Days*	*Hourly*	*6-17* *100-300*
Non-Spinning Reserve	Same as spinning reserve, but need not respond immediately; resources can be offline but still must be capable of reaching full output within the required 10 min				
	<10 min	*10 to 120 min*	*Hours to Days*	*Hourly*	*3-6* *100-400*
Replacement or Supplemental Reserve	Same as supplemental reserve, but with a 30-60 min response time; used to restore spinning and non-spinning reserves to their pre-contingency status				
	<30 min	*2 hours*	*Hours to Days*	*Hourly*	*0.4-2* *2-36*
Other Services					
Voltage Control	The injection or absorption of reactive power to maintain transmission-system voltages within required ranges				
	Seconds	*Seconds*	*Continuous*	*Year(s)*	*\$1-\$4/kvar-yr*
Black Start	Generation, in the correct location, that is able to start itself without support from the grid and which has sufficient real and reactive capability and control to be useful in energizing pieces of the transmission system and starting additional generators.				
	Minutes	*Hours*	*Months to Years*	*Year(s)*	-

* Prices are approximate ranges in \$/MW-hr for 2005 and include California, ERCOT, and New York.

$^{+}$ Ancillary services which loads may wish to sell are ***bolded and italized***

$^{\#}$ Up and down regulation prices for California and ERCOT are combined to facilitate comparison with the full-range prices of New York

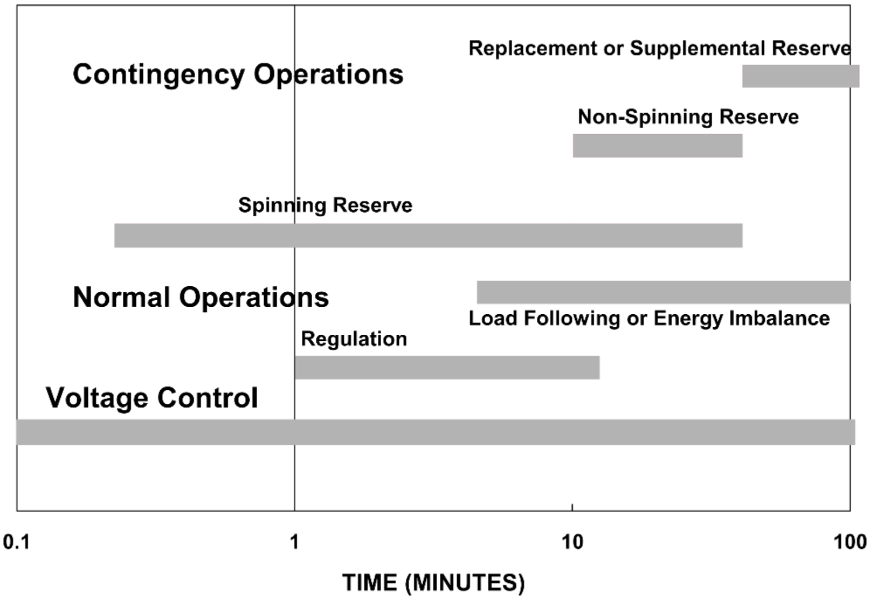


Figure 9 Response time and duration differentiate ancillary services (Kirby, 2006)

Figure 9 also show that in general, when a disturbance gets more critical or lingers around for a long time, the dispatch order of operating reserve starts from regulating, spinning and eventually supplementary or replacement reserve. In practice, parallel dispatch of different groups of operating reserves is possible based on the supply-side system operator' optimization which is usually based on cost of the ancillary services. The source of operating reserve comes from generators and energy storages. In the case of generators, it can be a specific generator only used for ancillary services or a general generator for usual power supply and also ancillary service as shown in *Figure 10*.

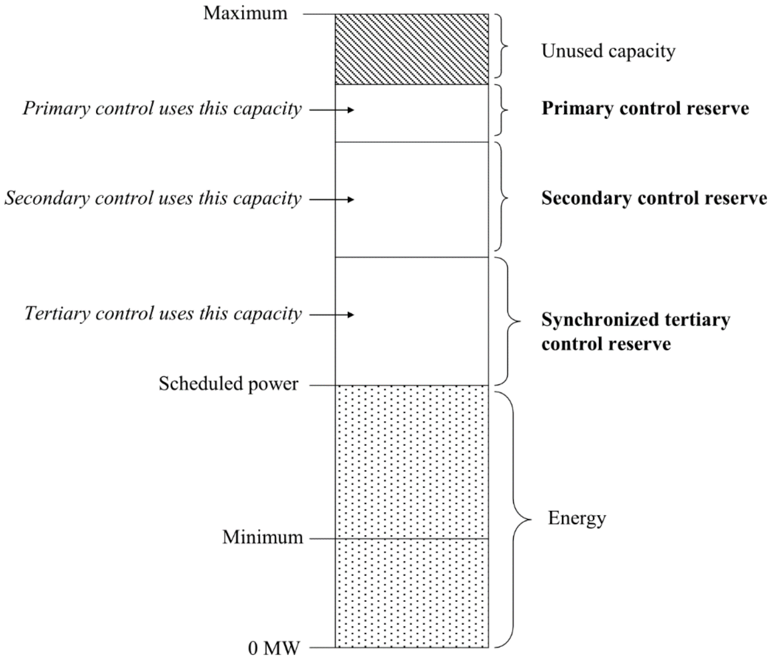
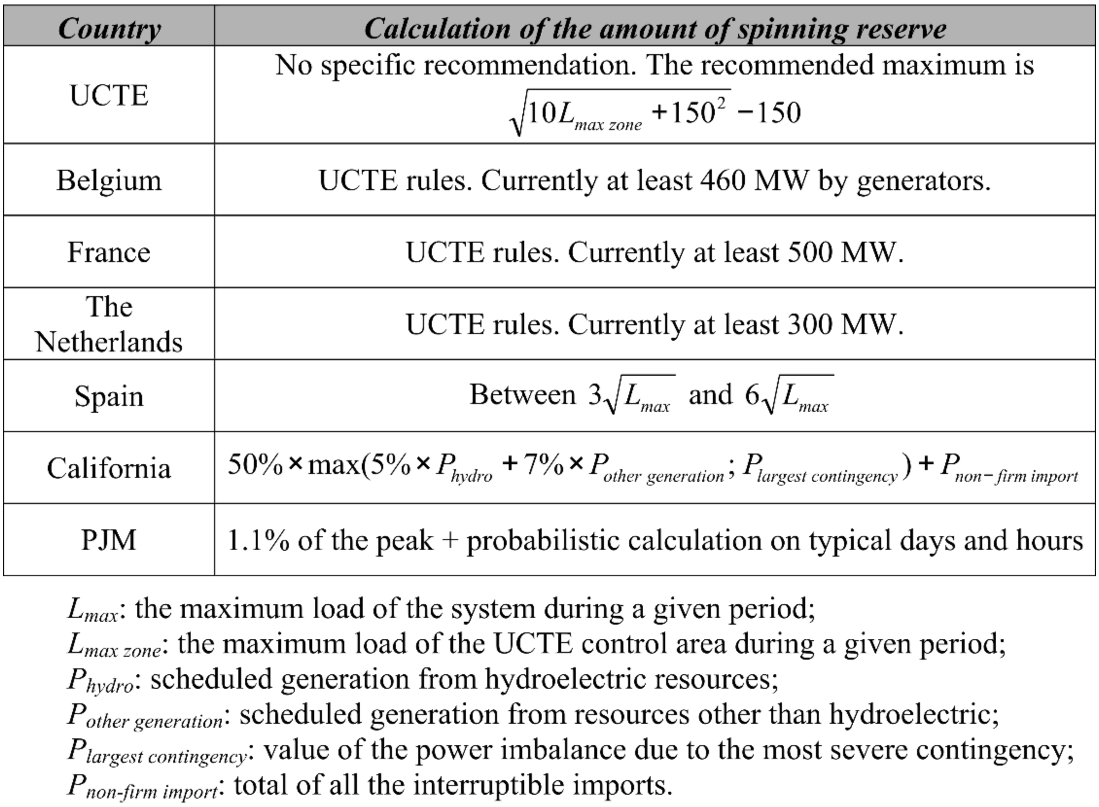


Figure 10 Allocation of the capacity of a generating unit that participates in all three levels of ancillary services (Rebours & Kirschen, 2005)

There is no universal standards on how to calculate the required amount of operating reserve. The practicing methodology used by each country or each power utility company in a country may vary. *Table 5* shows examples of calculation methodology used by some countries. In a smart grid system, demand response (DR) has been used in ancillary service to supplement the operating reserve (Please refer to *2.1.5.1 Potential of demand response*).

Table 5 Calculation methodology of operating reserve of different countries (Rebours & Kirschen, 2005)



Country	***Calculation of the amount of spinning reserve***
UCTE	No specific recommendation. The recommended maximum is $\sqrt{10L_{max\ zone}+150^2}-150$
Belgium	UCTE rules. Currently at least 460 MW by generators.
France	UCTE rules. Currently at least 500 MW.
The Netherlands	UCTE rules. Currently at least 300 MW.
Spain	Between $3\sqrt{L_{max}}$ and $6\sqrt{L_{max}}$
California	$50\% \times \max(5\% \times P_{hydro} + 7\% \times P_{other\ generation}; P_{largest\ contingency}) + P_{non-firm\ import}$
PJM	1.1% of the peak + probabilistic calculation on typical days and hours

L_{max}: the maximum load of the system during a given period;
$L_{max\ zone}$: the maximum load of the UCTE control area during a given period;
P_{hydro}: scheduled generation from hydroelectric resources;
$P_{other\ generation}$: scheduled generation from resources other than hydroelectric;
$P_{largest\ contingency}$: value of the power imbalance due to the most severe contingency;
$P_{non\text{-}firm\ import}$: total of all the interruptible imports.

2.1.4 Demand side management

Demand-side management (DSM) can be referred as any action taken place in demand side which results in change of energy consumption, whether increased or decreased. DSM is defined as programs that attempt to influence customer consumption patterns of electricity to match current or projected capabilities of the power supply system (Association of Edision Illuminating Companies (AEIC), 2009) and can be categorized as in *Figure 11*. The DSM is aimed to increase involvement and participation of demand users in the optimization of the operation of power supply and demand.

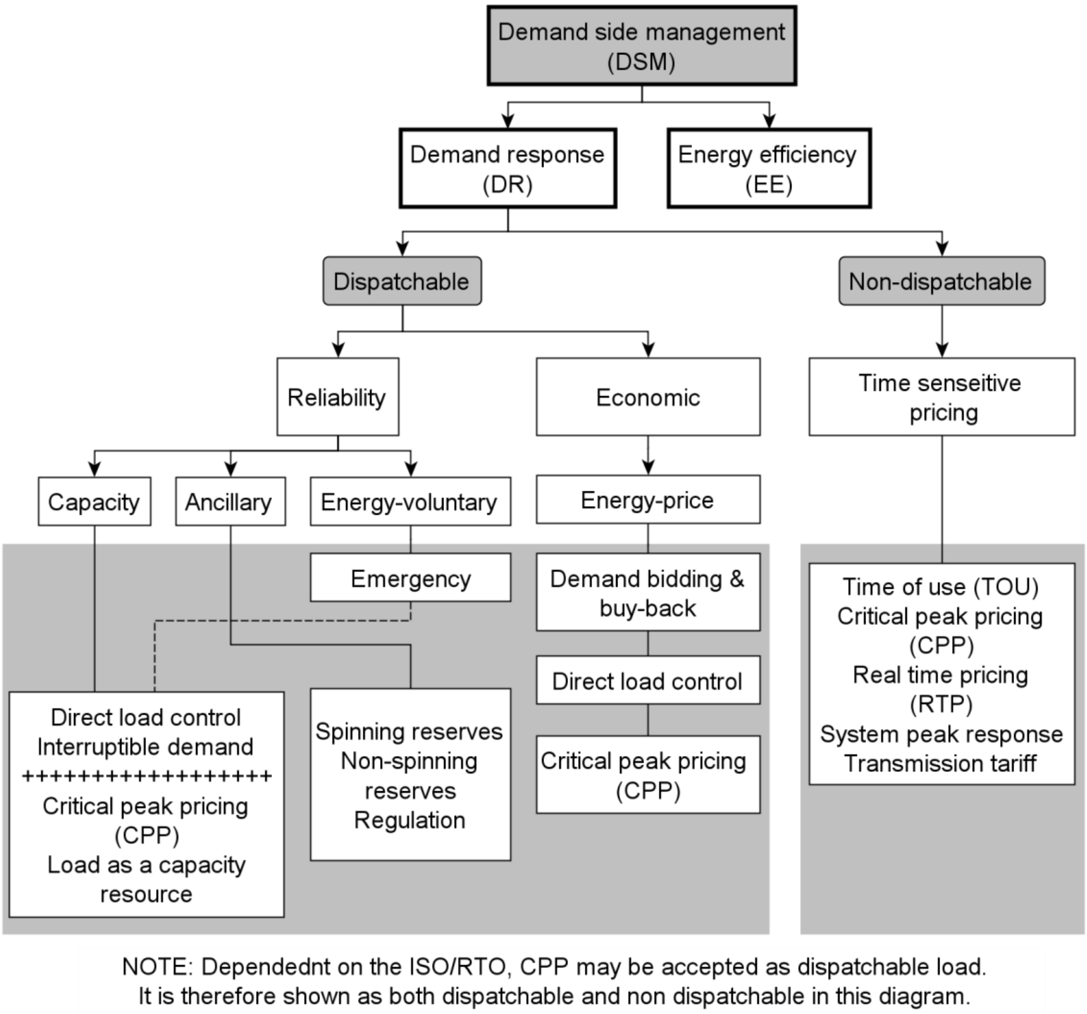


Figure 11 Demand-side management (Association of Edision Illuminating Companies (AEIC), 2009)

Demand response (Please refer to *2.1.5 Demand response* in the following section) is a component under the DSM but is always mistaken as interchangeable as the DSM, their differences and similarities are shown in *Figure 12*. However, in some places such as Ontario of the United States, the DSM is becoming almost equivalent to energy efficiency (IndEco Strategic Consulting Inc., 2004, p. 8). Energy efficiency related programs are usually capital expensive and require long payback time, for example, retrofitting or upgrading the building itself or the equipment inside the building.

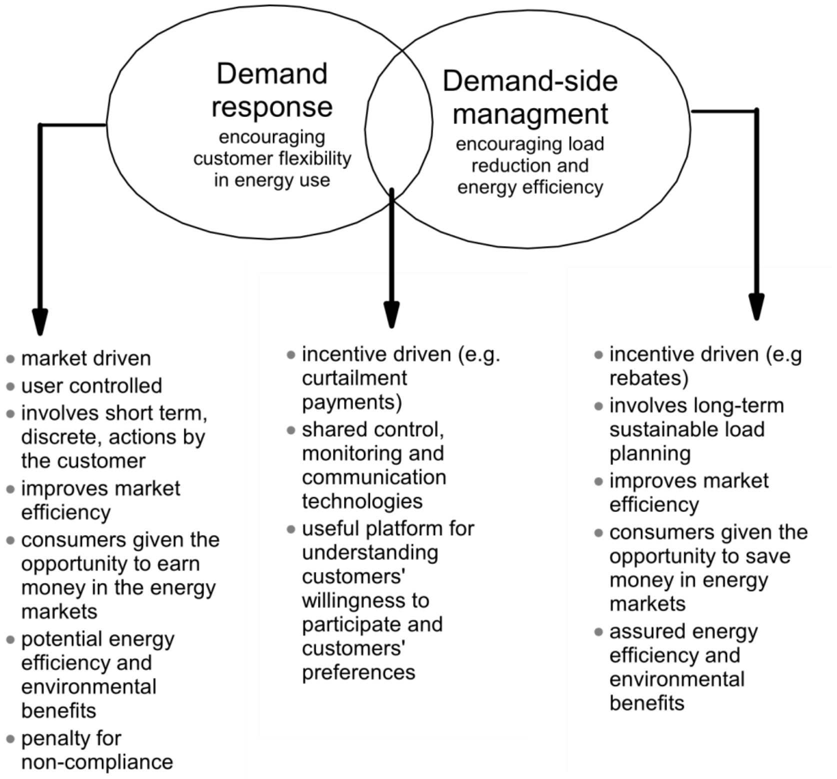


Figure 12 Similarities and differences of DM and DR (IndEco Strategic Consulting Inc., 2004)

2.1.5 Demand response

Demand response (DR) is one of the subsets of demand-side management. However, there are people who are confused and take them as interchangeable. Demand response can be defined as changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized (U.S. Department of Energy, 2006) (Federal Energy Regulatory Commission, 2006). A major discussion or debate about DR is regarding the tradeoff between its benefits and its negative effects on demand users’ convenience such as users’ comfort which subsequently influences other areas such as productivity, satisfaction and health. It is important to sustain users’ convenience while practicing DR. As also mentioned in the definition, DR program can generally be categorized in two groups: time-based and incentive-based programs. However, there are some power utility companies which have different ways of categorization and execution of DR program (Walawalkar, et al., 2010). *Figure 13* shows the categorization of DR into time-based and incentive-based programs. Definition of each subcategory program can be referred to in *Appendix 2*.

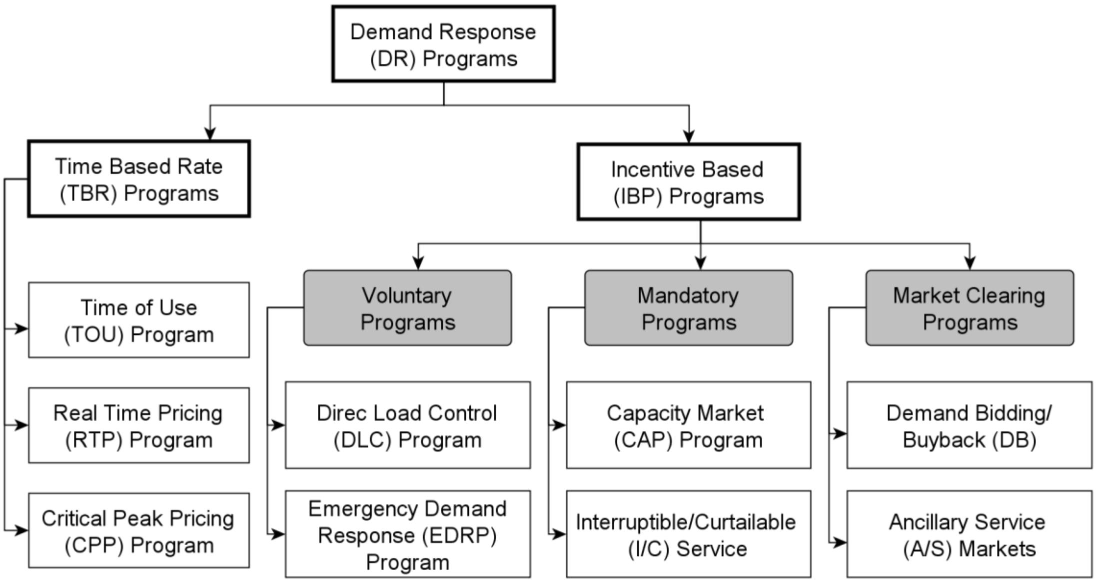
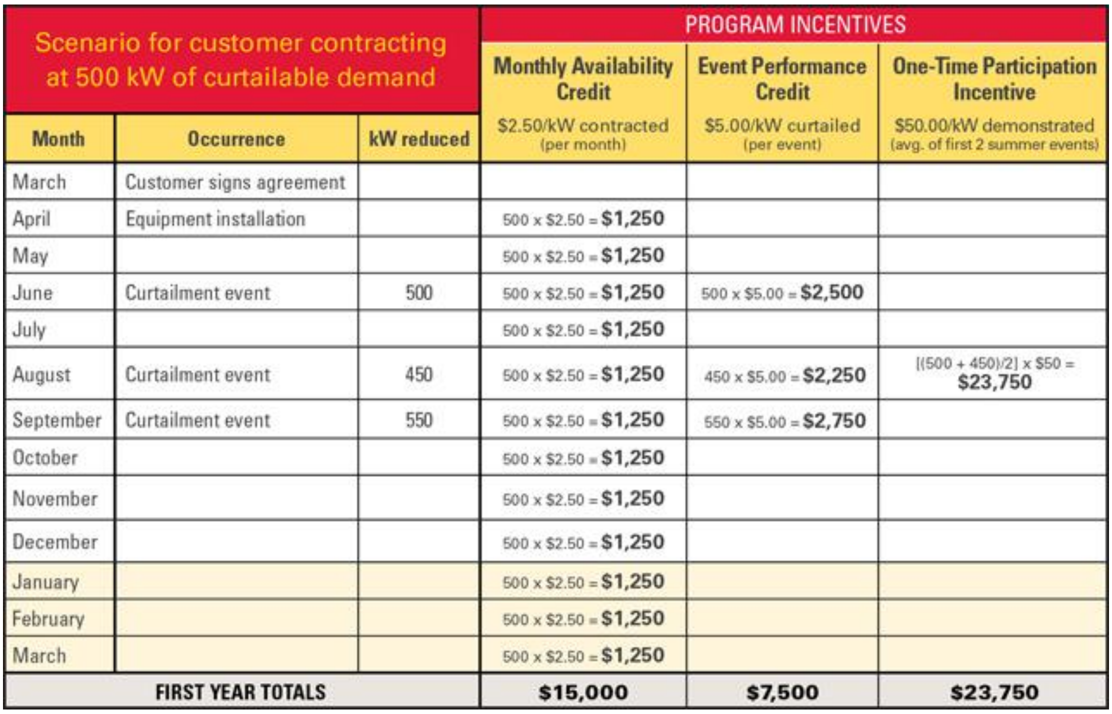


Figure 13 Categories of demand response programs (Moghaddam, et al., 2011)

Both types of DR programs basically aim to reduce power demand but there is a crucial difference between them in the perspective of a power utility company. In case of time-based DR program, a power utility company aims to achieve desired demand pattern by imposing different pricing rules to demand users, however in the case of incentive-based DR program, the power utility company treats the users' power demand as a virtual source of power supply [伊藤, 2012]. In case of time-based DR, the price of electric power is set higher during the time when power demand is high (peak demand) so as to discourage power consumption. In case of incentive-based DR, demand users or intermediary service providers such as DR aggregators will be requested by the supply-side system operators to change their power consumption when necessary, and incentive is given to those who respond to and fulfill the request, for example, in the form of discount of the electric bill. Figure 14 shows an example of incentive payment of a power utility company. There is also a saying that the nature characteristic of the former program is punishment-based and the latter rewarding-based. Some (Venkatesan, et al., 2011) argue that incentive-based DR is more suited for industrial consumers when time-based DR is more suited for residential consumers. However, many surveys and results of practice (*Figure 15* and *Table 6*) show that the incentive-based DR program is better received by demand users. Some believe (Friedman, 2009) (Piette, et al., 2006) that automation of DR is needed to make it a set-and-forget task for demand users.



Scenario for customer contracting at 500 kW of curtailable demand			PROGRAM INCENTIVES		
			Monthly Availability Credit $2.50/kW contracted (per month)	**Event Performance Credit** $5.00/kW curtailed (per event)	**One-Time Participation Incentive** $50.00/kW demonstrated (avg. of first 2 summer events)
Month	**Occurrence**	**kW reduced**			
March	Customer signs agreement				
April	Equipment installation		500 x $2.50 = **$1,250**		
May			500 x $2.50 = **$1,250**		
June	Curtailment event	500	500 x $2.50 = **$1,250**	500 x $5.00 = **$2,500**	
July			500 x $2.50 = **$1,250**		
August	Curtailment event	450	500 x $2.50 = **$1,250**	450 x $5.00 = **$2,250**	[(500 + 450)/2] x $50 = **$23,750**
September	Curtailment event	550	500 x $2.50 = **$1,250**	550 x $5.00 = **$2,750**	
October			500 x $2.50 = **$1,250**		
November			500 x $2.50 = **$1,250**		
December			500 x $2.50 = **$1,250**		
January			500 x $2.50 = **$1,250**		
February			500 x $2.50 = **$1,250**		
March			500 x $2.50 = **$1,250**		
FIRST YEAR TOTALS			**$15,000**	**$7,500**	**$23,750**

Figure 14 Example of incentive payment (Progress Energy, 2013)

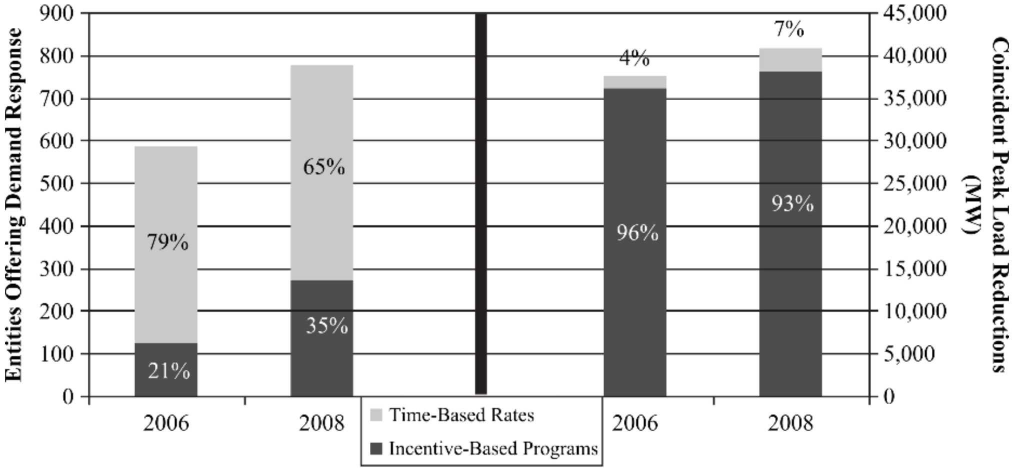


Figure 15 Estimated size of demand response resources in the United States (Cappers, et al., 2010) (Federal Energy Regulatory Commission, 2006) (Federal Energy Regulatory Commission, 2008)

Table 6 Survey showing incentive-based program is estimated to have more contribution to potential coincident peak demand reduction than time-based program (Cappers, et al., 2010)

	SPP			MWDRI		
	Incentive-based programs	Time-based rates	Voluntary response	Incentive-based programs	Time-based rates	Voluntary response
Survey respondents	26	5	4	99	12	N/A
No. of programs	36	5	6	122	19	N/A
Potential coincident peak demand reduction (MW)	1.352	200	N/A	4.406	321	N/A
Distribution of DR resources	87%	13%	N/A	93%	7%	N/A

DR program is a potential tool for the demand side to help in making the power operation resilient. However, it is also highly influential to demand users' lifestyles, activities, comfort and so on. DR also becomes a key factor in the debate of practitioners and academicians about whether users' convenience should be sacrificed in return of improved power operation, or users' convenience should be put on higher priority. However, due to data unavailability and prevention of any possibility of power outages, users' convenience is usually placed below system performance in the energy suppliers' priority list. The advanced notice, duration and frequency of DR are important factors to influence demand-side users' motivation and decision to participate in the program (*Table 9*, page *29* and *Figure 17*, page *29*). The DR program is still relatively a new and less tested feature of power grid systems or smart grid systems, however, its usage is expected to increase and shift from a passive application as a solution during emergency time of ancillary services, to an active application which integrates itself into every stage of power operation (*Table 7*). With the changes in market rules the opportunities have generally increased for DR program for participating in emergency, economic and ancillary service programs (Walawalkar, et al., 2010). Again, the aim is to ensure a good power quality and reliable power supply to the demand side.

Table 7 Shift of demand response program from passive to active application

Demand response features	Now	Near future
Application mode	Passive	Active
Frequency	Low	High
Purposes	Emergency, economy	Ancillary, emergency, economy, energy saving

2.1.5.1 Business models of demand response

There are many methods to categorized DR program. The categorization into time-based and incentive-based DR program is based on the perspective of supply-side operators regarding DR capacity. DR program can also be categorized by program objectives and by the motivation for demand user's engagement (*Table 8*) used to incent participation (NAESB & UCAlug, 2009). DR programs based on program objectives can be categorized into price response, reliability response and hybrid response. Apparently, many variations of DR program are available and it is important to offer flexible packages for the users to choose from. In addition, voluntary and mandatory DR programs are significant factors in determining the degree of uncertainty of available DR capacity.

Table 8 Categorization of demand response program by motivation for demand users (NAESB & UCAlug, 2009, p. 20)

Alternative pricing and rate structures (customer pays more for lack of DR)	Paid for performance (customer paid for DR)	Public cooperation (no financial exchange for DR)	Variable service Subscription (more customer choice using DR)
i. TOU ii. Block Rate iii. Day-ahead market rate iv. Dynamic Pricing (CPP, RTP, VPP) v. Demand Rates	i. Peak Time Rebate ii. Regional Operator Economic DR Programs iii. Demand Bidding for: • Forward Energy • Ancillary Service	i. Public Appeal for: • Peak Demand Conservation • Voluntary DR (Day-ahead)	i. Demand Subscription Service ii. Demand Limiting
i. Market-clearing price for energy ii. Discounted Rate for: • Direct Load Control • Interruptible Load • Curtailable Load (FSL, GLD) • Dispatchable Standby Generation	i. Regional Operator Emergency DR Programs • Interruptible Load • Curtailable Load • Dispatchable Standby Generation • Direct Load Control	i. Voluntary emergency DR ii. Voluntary emergency standby generation iii. Pre-planned voluntary interruptible/ curtailable load iv. Rolling Blackout	i. Premium Power ii. Better-Served-for-Performance (OBMC, PAP) iii. Priority Service

There are large demand users such as commercial and industrial buildings which have been long engaged in programs to curtail their power demand when requested. New target demand users such as residential buildings are small power consumers. Each type of demand users has different characteristics and therefore different business models of DR programs are available. Large demand users usually have resources, equipment and facilities to manage their power consumption that they usually sign up a DR program directly with power utility companies. However, small demand users usually participate in a DR program through an intermediary such as a DR aggregator. A DR aggregator makes profit from the incentive received from power utility companies. These business models of DR programs is shown in *Figure 16*. Among the reasons why DR aggregators are usually needed between power utilities companies and small demand users are as follows (NAESB & UCAlug, 2009):

- The collective size of the loads managed by a DR aggregator can meet the certain load size required by a power utility company which is not met by individual facilities. This is especially true in the wholesale market.

- The administrative/financial commitments required to participate in a DR program are more than an individual is willing to bear. However, a small demand user is supposed to specify the DR participation conditions to the load controller.
- An individual small demand user usually does not have the technical expertise or manpower available to enable and monitor the facilities performance during a DR event and is thus willing to leave that task to a DR aggregator. However, this situation may change when small demand users acquire the technology that will enable them to participate in DR programs.

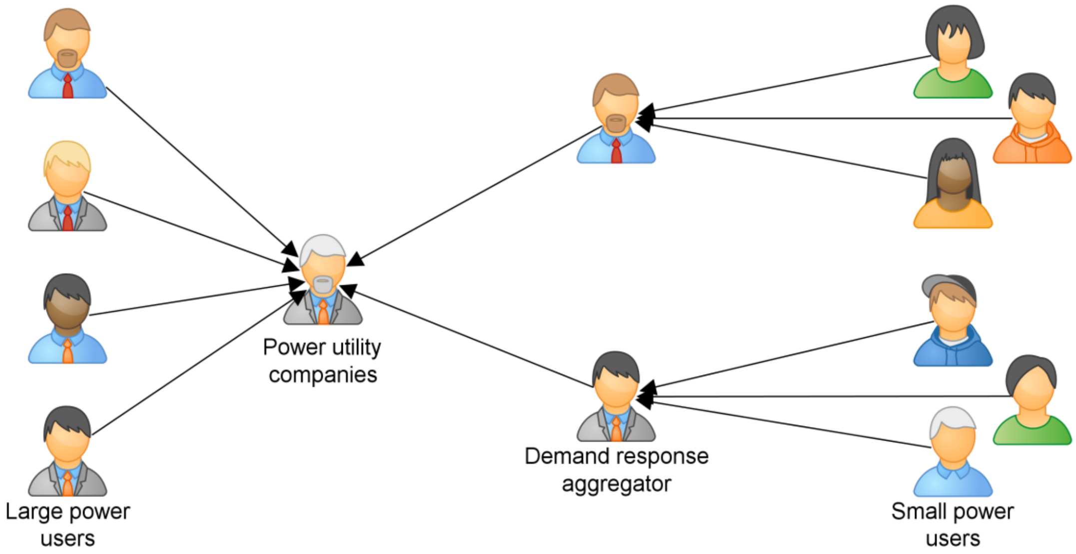
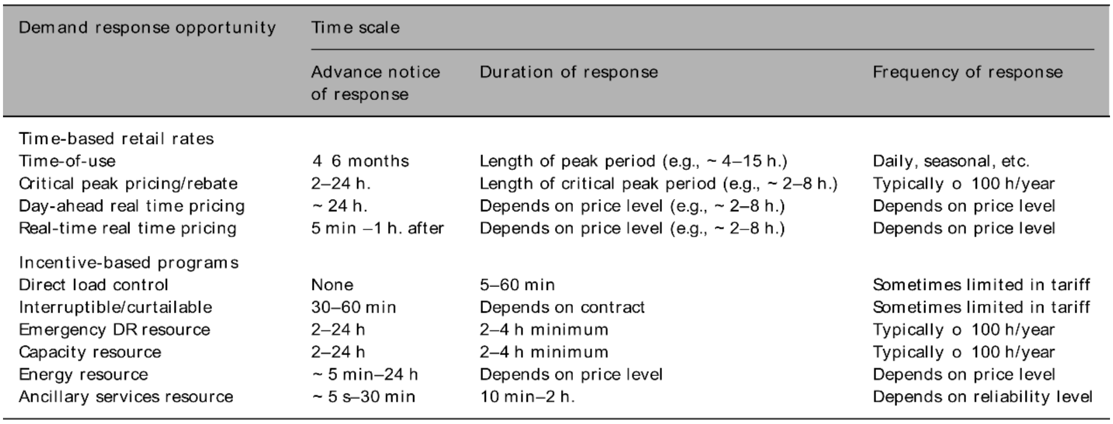


Figure 16 Business models of demand response programs

2.1.5.2 Potential of demand response

The full potential of DR is remained unexplored due to lack of knowledge about what it is and how to apply it (Bartusch, et al., 2011). The introduction of DR in the previous section has firmly supported the notion that DR can be used to enhance reliability of power grid systems by moderating peak demand (Cowart, 2001). *Table 9* shows the advance notice, duration and frequency of various DR programs. Some reports also have studied the advance notice requirements practiced by the supply side (*Figure 17*).

Table 9 Demand response programs and their time-related characteristics (Cappers, et al., 2012)



Demand response opportunity	Time scale		
	Advance notice of response	Duration of response	Frequency of response
Time-based retail rates			
Time-of-use	4 6 months	Length of peak period (e.g., ~ 4–15 h.)	Daily, seasonal, etc.
Critical peak pricing/rebate	2–24 h.	Length of critical peak period (e.g., ~ 2–8 h.)	Typically o 100 h/year
Day-ahead real time pricing	~ 24 h.	Depends on price level (e.g., ~ 2–8 h.)	Depends on price level
Real-time real time pricing	5 min –1 h. after	Depends on price level (e.g., ~ 2–8 h.)	Depends on price level
Incentive-based programs			
Direct load control	None	5–60 min	Sometimes limited in tariff
Interruptible/curtailable	30–60 min	Depends on contract	Sometimes limited in tariff
Emergency DR resource	2–24 h	2–4 h minimum	Typically o 100 h/year
Capacity resource	2–24 h	2–4 h minimum	Typically o 100 h/year
Energy resource	~ 5 min–24 h	Depends on price level	Depends on price level
Ancillary services resource	~ 5 s–30 min	10 min–2 h.	Depends on reliability level

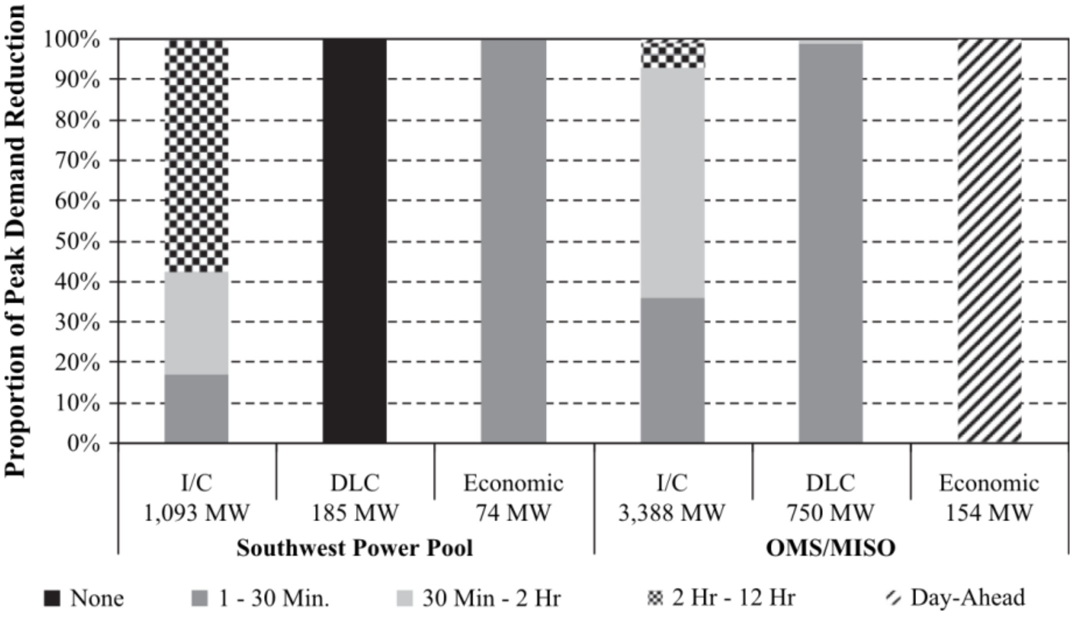


Figure 17 Advance notice requirements for demand response programs (Bharvirkar, et al., 2008) (Heffner, et al., 2009)

Many studies (Lawrence Berkeley National Laboratory, 2007) (Kirby, 2006) suggest that DR can be applied as a source of operating reserve. Many demand-side users can participate into any DR programs but what really matters is whether they will response to the request of changing their demands especially during time of emergency. Any loads being turned on can be a candidate of DR source, however, not all the DR sources can commit themselves when requested. This is a major reliability and uncertainty issue and has been the reason that many power utility companies are not using DR program as operating reserve. Most of the power utility companies nowadays only go for DR when the conventional operating reserve is incapable to recover the emergency situation. Proper agreement between supply and demand sides are needed to give authority to the supply-side system operators to control demand-side loads. In addition, a DR source needs to have performance characteristics in the aspect of dispatchability, latency and throughput capacity in order to be accepted as a source of operating reserve for ancillary service. DR programs not designed to alter the short term system load shape are deemed as non-dispatchable (Association of Edision Illuminating Companies (AEIC), 2009).

One significant requirement overcome the reliability and uncertainty issue of DR is the classification of the loads of the demand side. More studies about demand-side loads capable as a DR source and their dispatchability are necessary (*Table 10*). There are different buildings, activities and users in a city or community. Each building with different functions such as houses, offices and commercial buildings have difference in daily demand patterns and needs. Requesting for DR in day time may cause bigger problem in office buildings than residential buildings. Electric power is consumed in a building for various purposes, such as cooling and heating the space, making hot water, lighting, cooking, running production and so on. The potential, capability and suitability of the load of a certain purpose varies from the others and changes according to the time in a day.

There are also important arguments about the best way to make use of DR in the operation of power grid systems. Some (Kirby, 2006) argue that DR is better to use only for peak reduction but to others, for ancillary services especially emergency situation. And there is also suggestion to use it for both situations. Kirby explained that supply-side dispatch and demand-side dispatch (DR) are different, that DR is highly effective and responsive but at the same time it is best applied in emergency situation which requires faster, shorter and responsive ancillary services. As peak demand happens for long duration, as frequent as every day, and usually when the consumers are performing useful tasks, and therefore DR is not suitable for the purpose of reducing peak demand. The potential usage of DR for peak demand reduction, emergency and daily ancillary services require careful implementation to satisfy the interests of both supply and demand sides.

Table 10 Control strategies and applicable demand response programs for different customer types (Walawalkar, et al., 2010)

Customer type	Equipment/ building component	Control strategy	DR programs		
			Emergency (capacity)	Economic (energy)	Ancillary (Reg & Res)
Residential	Air conditioners	Cycling/forced demand shedding	O	O	O
	Water heaters	Cycling	O	O	O
	Pool pumps	Cycling	O	O	O
	Electric stove	Scheduling		O	
Commercial	Chillers	Demand limiting during on peak period	O	O	
	Chillers HVAC	Pre-cool bldg over night-storage		O	
		DX Forced demand scheduling	O	O	
	Refrigerator/ freezer	Prioritized demand shedding		O	
	Lighting	Scheduled on/off		O	
	Lighting	Scheduled dimming of selected circuits		O	
Industrial	Chillers	Demand limiting on time schedule		O	
	Electric furnace	Demand limiting through heat stages		O	O
	Electric furnace	Curtail (during peak period)	O	O	O
	VSDs	Limit output on scheduled basis		O	
	Well pumps	Defer during peak	O	O	
	Production equipment	Prioritized demand on selected units		O	
Restaurants/ shopping malls	HVAC	Chillers – demand limiting during peak		O	
	DX compressor	Forced demand shedding of multiple units	O	O	
	Refrigerator/ freezer	Prioritized demand shedding		O	
	Electric SToves	Scheduled pre-cookinge		O	

Adapted from Walawalkar R, Tongia R, Colburn B. Web-enabled metering and controls for demand response. In: Capehart BL, Capehart LC, editors. Web based enterprise energy and building automation systems. Lilburn, Georgia: The Fairmont Press, ISBN 0849382351; 2007. p. 299–314

2.1.5.3 Barriers of demand response

The previous section explained the underutilized potential of DR. As useful as it can be, there are many other barriers hurdling the growth and implementation of DR. Another major issue is the measurement of demand reduction achieved through DR program by the demand users (Association of Edision Illuminating Companies (AEIC), 2009). Kim has reviewed and reported a comprehensive barriers of DR program, which is summarized as below (Kim & Shcherbakova, 2011).

- Consumer barriers
    - Consumer knowledge
    - Availability of technology
    - Information feeds
    - Response fatigue
    - Technology cost and financing
    - Potential savings
    - Satisfying behavior in switching patterns
- Producers barriers
    - Investment recovery
    - Promotional responsibility (Greening, 2010)
    - Managerial incentives
- Structural barriers
    - Program structure (rates, technology, etc.)
    - Regulatory (restructuring) process and policy support EU energy policies are more focused on energy efficiency and DSM issues, rather than DR (Torriti, et al., 2010).

2.1.6 Generation portfolio

Conventionally, electric power is generated from the supply-side centralized generation which is located far away from the demand-side users and the generators are usually of high capacity and using fossil fuel as the generation source. In a smart grid system, distributed generation which is characterized by its location being in the demand side and its small capacity. Distributed generation has also encouraged and accelerated the generation of renewable energy because most buildings especially residential buildings tend to invest in photovoltaic panels or micro wind turbines than on-site diesel generators. When the generated power supply is more than the demand of the buildings, the owners can choose to store the surplus power into a battery storage or sell it back to power utility companies. Germany and Japan are among the early countries that implemented feed-in tariff to boost the adoption of distributed generation in the demand side. However, recently 2012, both countries has changed the policy to reduce the feed-in tariff payment due to the declined cost (Fulton, et al., 2012) [資源エネルギー庁 新エネルギー対策課, 2012].

Distribution generation is expected to have a significant role in the smart grid systems in the near future because most of the governments of many countries have been backing and boosting the investment of distribution generation. Certainly, distribution generation have many benefits as mentioned before. However, more does not always guarantee good implication as many studies have shown that high adoption rate of renewable energy generation especially wind power which is highly unpredictable among all types of energy, can produce less optimum result (Arun, et al., 2009) (Denholm & Hand, 2011). When the percentage of distributed generation is increasing, at the moment it still cannot completely replace centralized generation because of the intermittent nature of its generation.

2.2 Disturbances to power grid systems

A power grid system is a complex system spanning from one place to another located far away and the transmission and distribution network systems connecting the supply and demand sides are usually built on the ground. A power grid system is surrounded with various external and internal threats. *Figure 18* gives a comprehensive classification of disturbances to power grid systems. Any disturbances happened can reduce its functionality such as causing power imbalance and physical damages to equipment which subsequently lead to troubles in demand side.

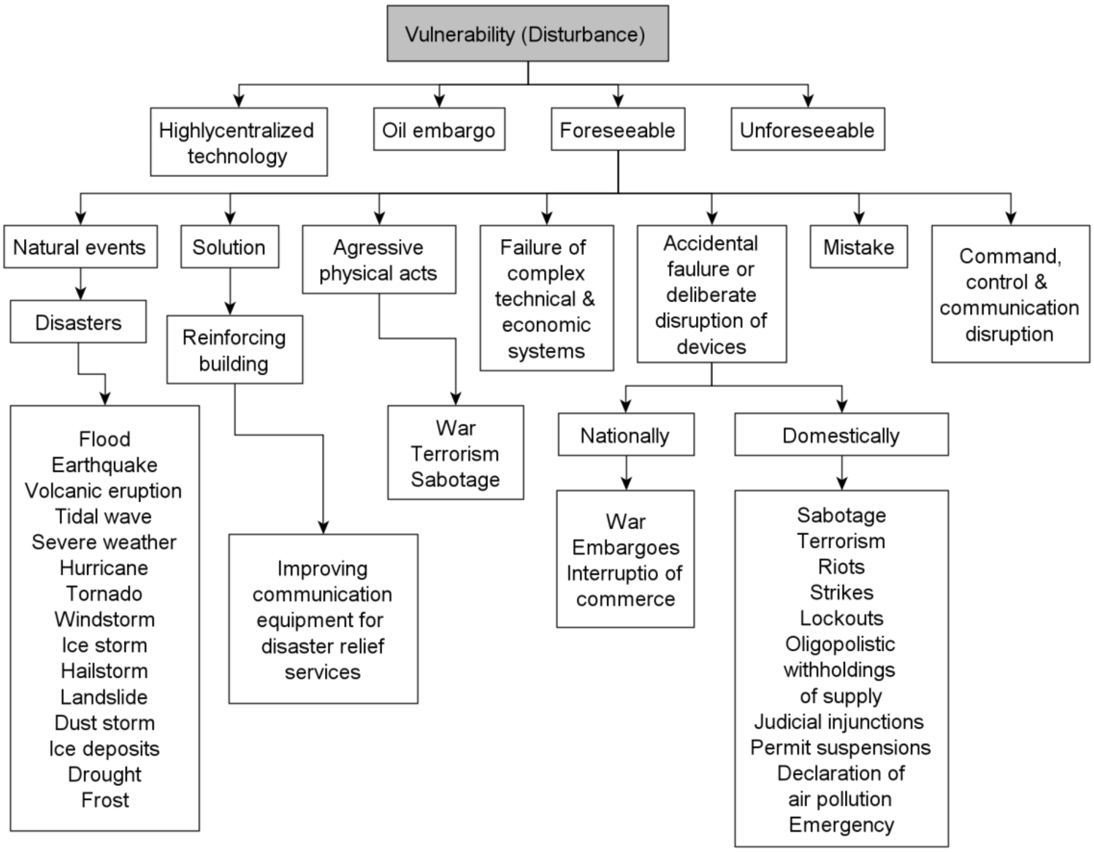


Figure 18 Disturbances to power grid systems (Lovins & Lovins, 1947)

Disturbances can happen in any level or place in the power grid system: generation, transmission and distribution. It can be as small as a short-circuit failure in a consumer's end or as catastrophic as causing huge damages and loss of lives. The Tohoku Earthquake in 2011 was so critical that Japanese reconsidered about the goals of the Japanese smart grid system. Before the disaster, Japanese goal was to ensure stability of the power grid system to accommodate large amount of renewable energy generation but after the disaster the consideration of making the power grid system to be resilient against disasters or disturbances is also included as one of the goals of the Japanese smart grid system. A smart grid system can be a solution and also a new problem if it is implemented wrongly (For example of problem smart grid systems, please refer to *2.1.6 Generation portfolio*). The problems caused by disturbances to the power grid system can be categorized according to the time and duration characteristics of the problem (*Figure 19*).

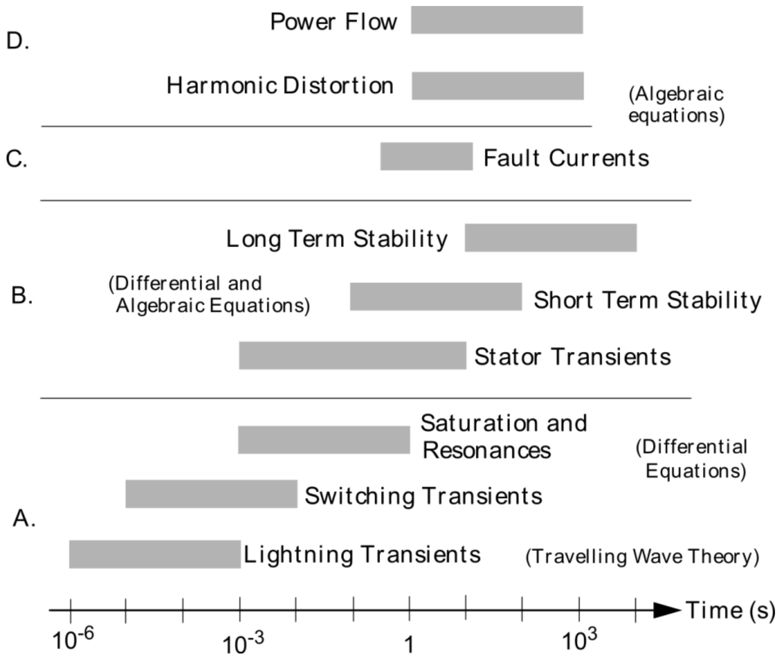


Figure 19 Dynamic phenomena in a power system. In the figure approximate time scales are given and types of mathematical models used. A: Electro-magnetic transients. B: Synchronous machine dynamics. C: Quasi steady state phenomena D: Steady state phenomena. (Andersson, 2008)

There are many ways to deal with disturbances for a power grid system, for example, hardening the system with better safety measures and designs, preparing backup or redundant equipment and better organizational control and operation. Most of them belong to preventive or protective methods which attempt to avoid the occurrence of disturbances or failure of system. However, a well-protected system is high cost because it is supposed to cover all risks, to anticipate all threats to that system and apply protective measures to the system (Hoffman & Nilchiani, 2008). According to Hoffman, a resilient system focuses on the outcomes of the risks and thus can be cost effective. The way of thinking of resilience theory regarding threats and disturbance to a system can be represented by *Figure 20*.

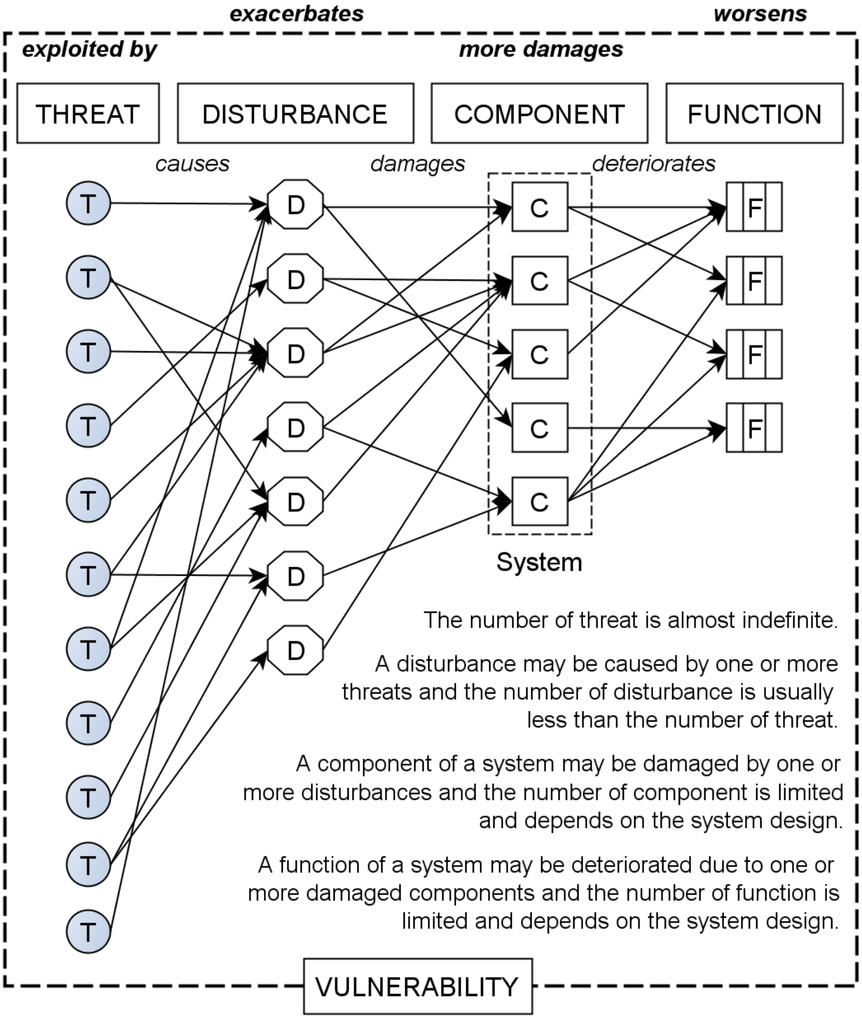


Figure 20 Exploitation of vulnerability by threats exacerbates the damages to system

2.2.1 Blackout and restoration

A major goal of power operation is power balance but it hardly exists and therefore balancing of power supply and demand or ancillary services are needed. Figure 21 shows that ancillary services can becomes from a common ancillary situation to a critical emergency ancillary situation. If all measures performed and none is sufficient to stabilize the power grid system, blackout or power outage will happen, either totally or partially and then restoration will start. A blackout can happen in any stages and the objective of restoration is same to ancillary services, which is to restore the system, achieve power balance and provide reliable power supply to demand-side users.

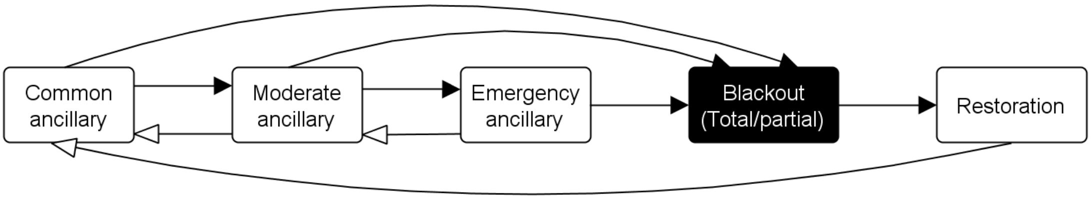


Figure 21 Mechanism of blackout and restoration

A research (Agneholm, 1996) related to how energy consumption changes after the occurrence of a blackout found out that processing industries such as the pulp and paper industry, the iron and steel industry and the chemical industry will consume considerably less power during the hours after an interruption as compared to the pre-outage situation. This is due to the fact that these industries have sensitive processes which take a long time to restart. Agneholm also found out that due to the impact from the thermostatically controlled loads such as electrical heating, freezer, and refrigerator, the residential sector will lead to a significant increase in power consumption following an interruption.

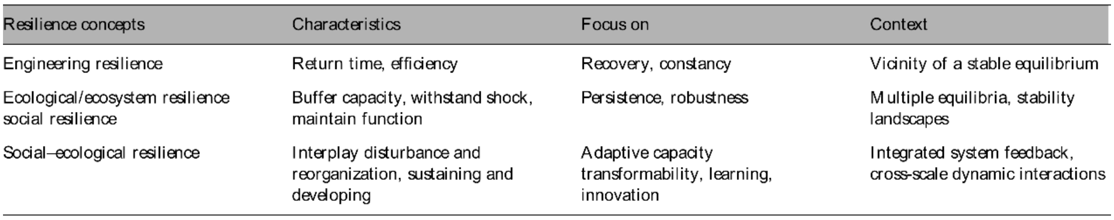
2.3 Resilience

A literal meaning of resilience is the ability of a substance or object to spring back into shape, or the capacity to recover quickly from difficulties (Oxford Dictionaries, n.d.). Other interchangeable choices of words carrying the same meaning are the resiliency and resilient capacity. A paper written by Carl Folke provides informative knowledge about the historical development of the study of resilience (Folke, 2006). In the paper, it is stated that resilience study first emerged in the field of ecology in the 1960s in the research paper of Holling (Holling, 1961) (Holling, 1973) studying on the resilience and stability in ecological systems. Other early works related to the resilience were done by Lewontin and Rosenzweig (Lewontin, 1969) (Rosenzweig, 1971). And from there and then onwards, the concept or theory of resilience has started to expand into other disciplines of study, such as physics, mathematics, social science, engineering and so on. In most situations, the majority agree that resilience of a system is described by the resistance capacity and recovery rapidity of the system.

2.3.1 Type of resilience

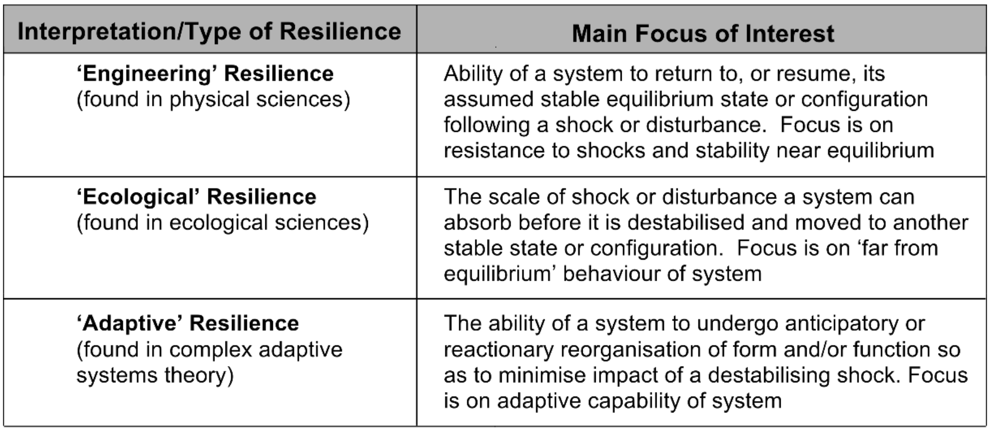
So far, there is no single universal definition of resilience yet, almost every field of study has its own definition of resilience and within each field of study and there are many variation of definitions among the researchers. A few researchers have attempted to classify resilience: Folke classified the concept of resilience into three types: engineering resilience, ecological resilience and social-ecological resilience (*Table 11*), according to Martin there are three types of resilience: engineering, ecological, and adaptive resilience (*Table 12*), and Sinclair mentioned three types of resilience: engineering, organizational and ecological resilience (*Table* 13).

Table 11 Type of resilience of Folke (Folke, 2006)



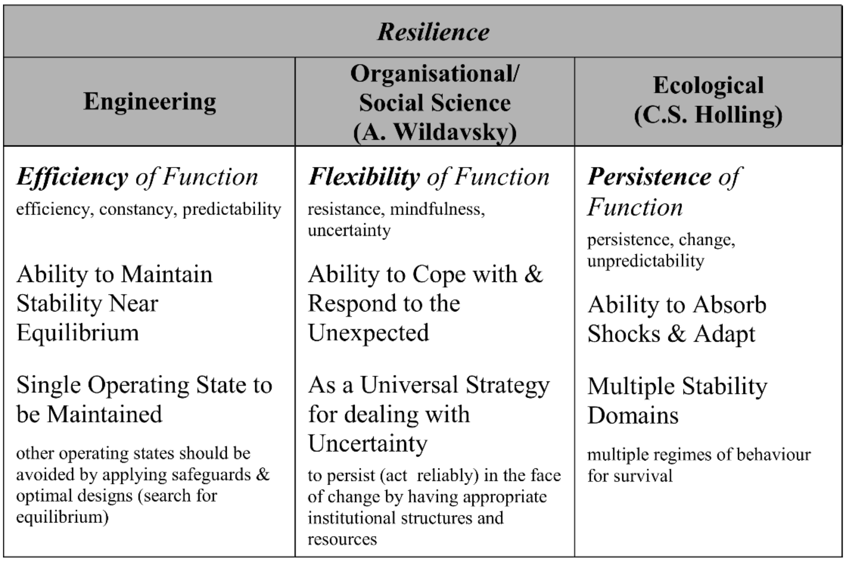
Resilience concepts	Characteristics	Focus on	Context
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological/ecosystem resilience social resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibria, stability landscapes
Social–ecological resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity transformability, learning, innovation	Integrated system feedback, cross-scale dynamic interactions

Table 12 Type of resilience of Martin (Martin, 2011)



Interpretation/Type of Resilience	Main Focus of Interest
'Engineering' Resilience (found in physical sciences)	Ability of a system to return to, or resume, its assumed stable equilibrium state or configuration following a shock or disturbance. Focus is on resistance to shocks and stability near equilibrium
'Ecological' Resilience (found in ecological sciences)	The scale of shock or disturbance a system can absorb before it is destabilised and moved to another stable state or configuration. Focus is on 'far from equilibrium' behaviour of system
'Adaptive' Resilience (found in complex adaptive systems theory)	The ability of a system to undergo anticipatory or reactionary reorganisation of form and/or function so as to minimise impact of a destabilising shock. Focus is on adaptive capability of system

Table 13 Type of resilience of Sinclair (Sinclair, 2009)



Resilience		
Engineering	**Organisational/ Social Science (A. Wildavsky)**	**Ecological (C.S. Holling)**
Efficiency *of Function* efficiency, constancy, predictability	***Flexibility*** *of Function* resistance, mindfulness, uncertainty	***Persistence*** *of Function* persistence, change, unpredictability
Ability to Maintain Stability Near Equilibrium	Ability to Cope with & Respond to the Unexpected	Ability to Absorb Shocks & Adapt
Single Operating State to be Maintained other operating states should be avoided by applying safeguards & optimal designs (search for equilibrium)	As a Universal Strategy for dealing with Uncertainty to persist (act reliably) in the face of change by having appropriate institutional structures and resources	Multiple Stability Domains multiple regimes of behaviour for survival

In general, it is agreed that there are at least two types of resilience, namely the ecological and engineering resilience. The engineering resilience emphasizes the ability of a system to stay stable within its only one equilibrium. In case of two systems receiving an identical disturbance, the system that becomes unstable first is considered as not resilient, or the system that returns to its stable equilibrium faster than the other is more resilient. On the other hand, the ecological resilience emphasizes that there is more than just one equilibrium of a system that when a system cannot sustain its stable equilibrium, the system will move towards to another stable equilibrium which is configured differently than the previous state. In this case, a system is more resilient if it can return to its initial equilibrium faster or it can keep itself stable without having to go into another stable equilibrium than another system. *Figure 22* shows the graphical representation of engineering and ecological resilience.

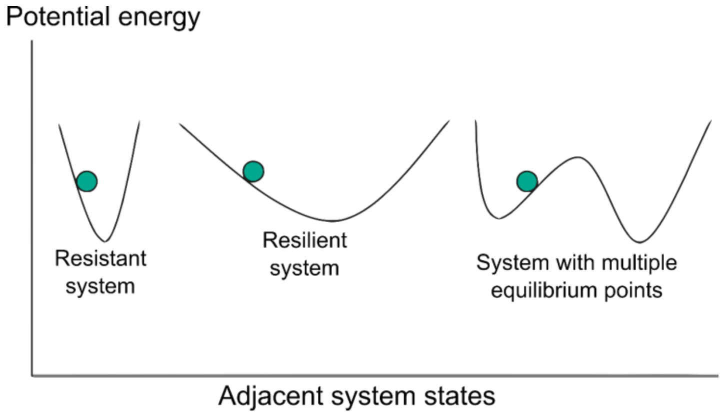


Figure 22 Graphical representation of engineering (center) and ecological resilience (right) (Fiksel, 2003)

There are also many books and researches discussing deeply about the theory of resilience and attributes of resilience (Hollnagel, et al., 2006) (Jackson, 2010) (Comfort, et al., 2010). Examples of resilience attributes are included in *Appendix 3* and *Appendix 5*.

2.3.2 Assessment of resilience

The concept of resilience has been applied in many fields of study and many assessment methodology of resilience has been proposed. Resilience is assessed either using quantitative, qualitative or a hybrid method. Most of the quantitative assessment are usually based on bottom-up approach. Attributes representing the resilience of the subject system of interest is decided and then metrics or indicators representing those attributes are quantitatively defined. Resilience of the system is eventually a function of those attributes indicators. In case of quantitative assessment, there is a study which defines resilience with the cost of restoration of lake eutrophication by using a mathematical methodology known as viability approach (Martin, 2004). There are many more case studies applying the viability approach in the assessment of resilience which are included in a research article edited by Deffuant and Gilbert (Deffuant & Gilbert, 2011). In the field of water network system, Gao measured resilience of a water pumping station by analyzing the system recoverability from two points of view: reconfiguration and replacement (Gao, 2010). On the other hand, there is a study about resilience of information technology (IT) service which assesses resilience based on reliability, availability, security, interoperability and maintainability of the IT system (Ramanathan & Lac, 2009).

Some of the assessment results of resilience can be graphically represented to give a better understanding of the result. The graphical representation or expression of resilience varies case by case depending on how resilience is defined and the authors' judgments. In the case where resilience is assessed with the dimension of time (such as recovery time), the performance of system resilience over time is frequently expressed in a graph as shown in *Figure 23* which is also known as a recovery curve (Chang & Shinozuka, n.d.) (Bruneau, et al., 2003).

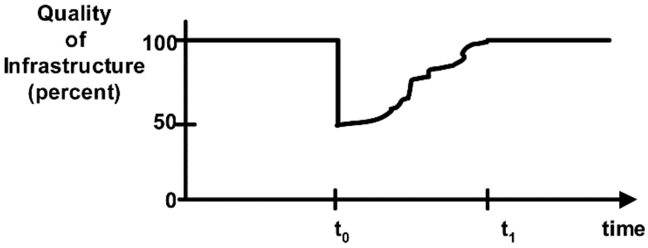


Figure 23 Performance of resilience over time

Garbin and Shortle proposed three methods to graphically express the assessment of resilience of network-based infrastructure system. In *Figure 24*, the vertical and horizontal axes of the three graphs represents the network performance and percentage of damage, respectively. Resilience of the network system can either expressed through the shape of the graph line (*Figure 24*a), area below the graph line (*Figure 24*b) or the gradient of a single point along the graph line (*Figure 24*c). Each method has different characteristic and representation of resilience.

Appendix 8 Approaches to measure or assessing resilience*Appendix 8* further explains other approaches and methods to measure or assess resilience proposed by some researchers. Assessment if resilience is important and some of its uses and benefits are listed below (Briguglio, et al., n.d.).

- Supporting decision-making, setting targets and establishing standards
- Monitoring and evaluating developments

- Deriving quantitative estimates
- Dissemination of information and drawing attention to the issue
- Focusing the discussion
- Promoting the idea of integrated action

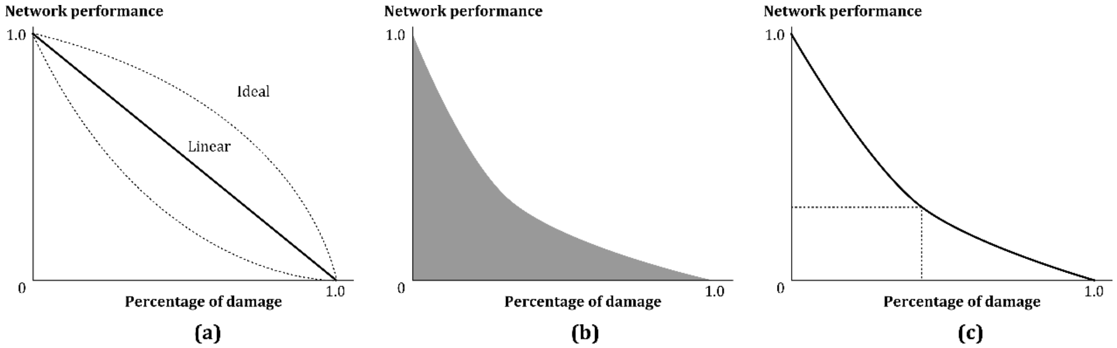


Figure 24 Three different expressions of resilience (Garbin & Shortle, 2007)

2.3.3 Resilience of power grid systems

The power grid systems around the world have their own respective problems (*Table 2*, page *14*) and can be considered as less resilient. What is good and bad resilience? And what is a resilient power grid system and one that is vulnerable or less resilient? The most fundamental function or objective of a power grid system is to supply electric power to demand-side users. The power supply is needed by the users to perform various activities to support their lives and create comfortable and productive environment especially inside buildings where human spend most of their time. However, various threats are likely to disturb the normal operation of the power grid systems and sometimes the power grid system including both supply and demand sides is not able to fulfill its functions at a satisfactory level. Resilience performance of a power grid system is dependent on how it is able to sustain its functions or objectives, in any given time especially throughout the occurrence of disturbances.

Compared to other fields of study, the concept of resilience is still relatively new in the study of power grid systems. However, a few researches about the assessment of resilience of power grid systems have been available and many assessment methodologies have been proposed (Hoffman & Nilchiani, 2008). Just like any field of study, the assessment methodology is based on quantitative, qualitative and hybrid approach. However, in the case of power grid systems which is engineering-based, quantitative assessment is preferred and most of the existing literature are based on quantitative approach. In addition, bottom-up approach is often used. For an instance, Molyneaux and others calculated a robust measure of national power system resilience by analyzing each step in the process of transformation from raw energy to consumed electricity and they used seven indicators to represent resilience of the national power system (*Figure 25*).

$$\text{Resilience index} = \sqrt[7]{a.b.c.d.e.f.g}$$

where:
a = non-renewable fuel used index
b = generation efficiency weighted for non-renewable fuel dependence index
c = distribution efficiency index
d = carbon intensity index
e = diversity index
f = redundant electricity for use in GDP index
g = reliance on imports index

Figure 25 Metrics or indicators used in resilience index (Molyneaux, et al., 2012).

In Reed and others' study of assessing resilience of power delivery system, they applied the definition of engineering resilience, used input-output models, and defined fragility and quality as the resilience attributes (Reed, et al., 2009). Resilience of power grid systems was treated as a problem of supply chain management by Montoya. Montoya used bottom-up approach and linear programming model, defined capacity of transmission line, reliability, recovery capability and vulnerability as the resilience attributes (*Figure 26*).

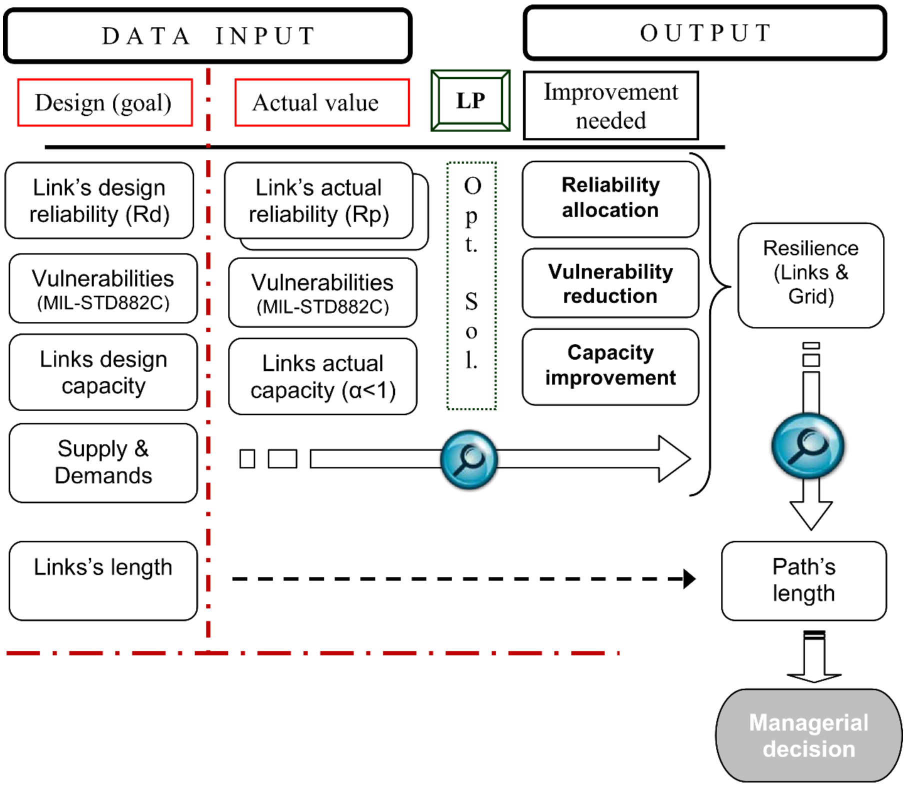


Figure 26 Resilience assessment model (flowchart) of power grid systems (Montoya, 2010)

Chapter 3

Proposal of assessment methodology

The content from this chapter onwards is the original works of this study. However, it must be made clear that the author also adopted and modified existing methods and models from other existing works and literature in this study, and clarification and source citations are given where relevant. This chapter explains the frameworks which combines together to form the assessment methodology of this study. The proposed methodology will be applied to develop an assessment model to carry out case-study analysis to study the effect of demand response on energy resilience of communities.

3.1 Introduction

The assessment methodology proposed here is generic that it should be applicable to most systems and most field of studies. The proposed assessment methodology is based upon the author's ideas and also existing methods and models from other existing works and literature.

The main focus of this chapter is the proposal of alternative resilience definition by the author for use in this study. The proposed resilience definition is very important to this study because the following works including the proposed assessment methodology and indicators are depending on the proposed resilience definition. Besides that, the structure of assessment methodology which consists of concept, indicator selection and analysis frameworks are introduced as well.

3.2 Structure of assessment methodology

The author proposed that an assessment methodology requires a concept framework to establish fundamental and well-studied understanding of resilience concept, an indicator selection framework as a guideline to select assessment indicators, and an analysis framework to use to assess system resilience during planning and design stages. The structure of resilience assessment methodology proposed in this study is shown in *Figure 27*. The concept framework explains and discusses about the definition of resilience and its attributes, and also how characteristics and mechanism of a system in its own operating environment gains or loses the property of resilience. The indicator selection framework describes the series of processes in selecting and looking for indicators suitable for the purpose of assessment. The analysis framework explains the available methods of modeling, simulation and analysis which will be used to develop analysis model for simulating daily power operation for assessment purpose later.

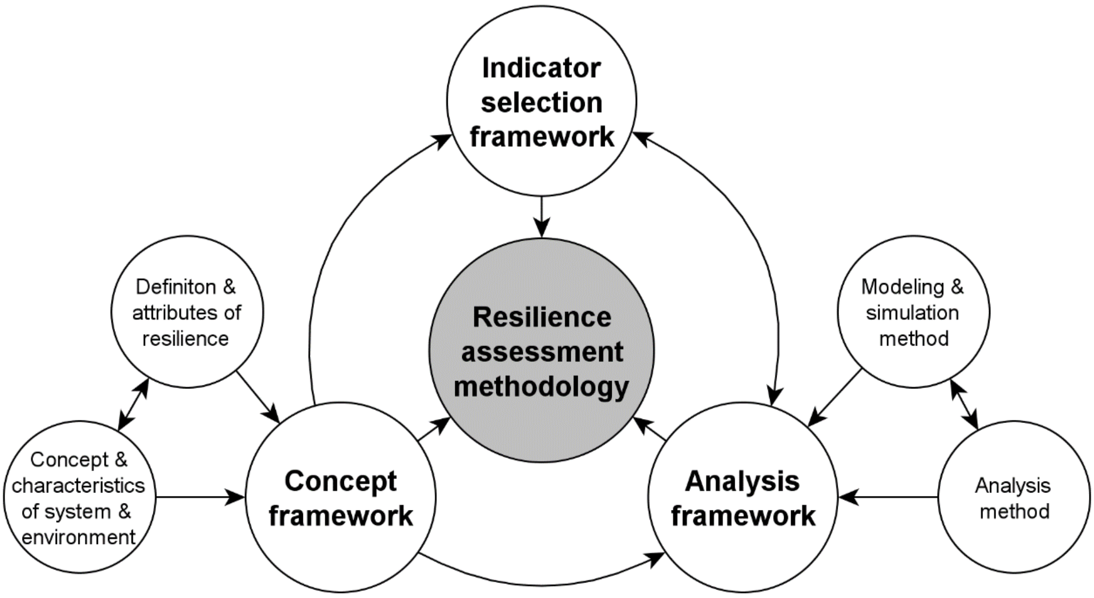


Figure 27 Structure of resilience assessment methodology

3.3 Definition of resilience

Assessing resilience is the main focus of this study and therefore a resilience definition for this study context is required. Resilience for this study context is defined as follows.

> *The ability of a system depending on its own responsiveness and vulnerability to maintain its system functionality throughout any disturbances. (障害時に機能を維持するためのシステムがもつ能力。その能力はシステムの応答性と脆弱性に依存する。)*

This resilience definition is very significant in this study because the assessment methodology is proposed completely based on it. Many existing definitions describe resilience as a capacity to absorb or adapt to shocks or disturbances (resistance capacity), the time a system takes to recover from damages (recovery rapidity). The author sees that eventually what matters the most is the objectives, goals, purposes or functions (as used in this study) of a given system, whether they are working properly above a minimum level or not. Every system is designed with at least a function. A function is part of the attributes or properties of a system which is at the same time supported by other attributes of the system. Many studies agree that adaptability is a significant attribute of a resilient system because a highly adaptable system can quickly response to the change of operating environment and avoid undesired outcomes. Eventually, the fundamental aim is to keep the system working within desired conditions that the system should do something (respond). For example, when a fire happens in a building, how quick a team of firefighters is dispatched affects the chances of putting out the fire, however, they may still fail to put out the fire even if they arrive early and vice versa. In this analogy, the function or goal of putting out the fire in the building is the resilience performance of the fire event, whereas the arrival timing and action of putting out fire by the firemen are the actions (response to the disturbance: fire) affecting the final outcome and they are the supporting performance of resilience. In this study, resilience performance is indicated and determined by the level of functionality of a system. Other system attributes which can significantly affect resilience performance are also taken into account in the assessment.

The proposed resilience definition is the result of an analysis of literature related to resilience study (*Figure 28*). Basically, once the keyword: resilience was decided, abundant literature from various fields of study describing the concepts, attributes, definitions, assessment and case studies of resilience were collected and reviewed. The attributes of resilience proposed by many authors was sorted into some lists (*Appendix 3*, *Appendix 4* and *Appendix 5*) to find out what are the top and most representative attributes of resilience agreed by most authors. A study of Montoya which also analyzed the top attributes of resilience was also reviewed (Montoya, 2010). It is important to find out the most representative attributes of resilience so that these resilience attributes can be used as the indicators of resilience of a subject or system.

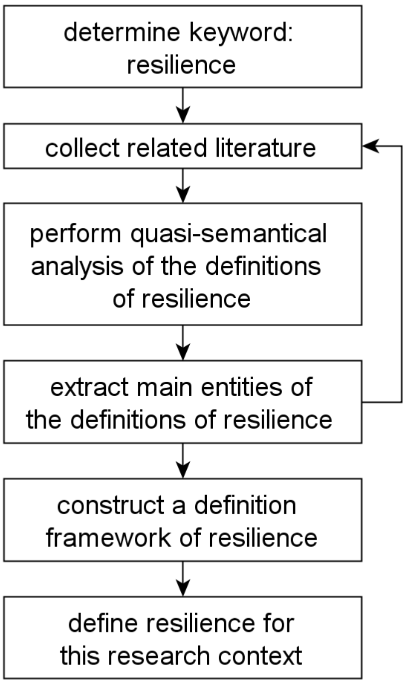


Figure 28 Successive steps to define resilience

From the numerous literature of resilience study, a large number of resilience definitions proposed by many authors was collected and analyzed. The analysis performed to the resilience definitions is known as quasi-semantical analysis in this study which aims to extract information (entities) from those definitions. This quasi-semantical analysis was used to find out the interpretation of the meaning of resilience by each author. Throughout the analysis, a general structure of the resilience definition was identified as shown in the *Figure 29(a).* A resilience is usually defined as something (as responding to *what is it?*), which belongs to a subject or system (as responding to *whose is it?*), to do something or achieve some purposes (as responding to *what does it do?*). By analyzing the resilience definitions following the identified general structure, *Appendix 6* was made. By putting the extracted information back into the general structure of resilience definition, it could be understood that a resilience is a state of a system to respond to the occurrence of disturbances (*Figure 29(b)*). The response from the system can take place before, during and after the occurrence of a disturbance and the reason why those responses are taken is to achieve functions assigned to the system. Up to this step, it is understood that functionality of a system is the main concern why the system responses to the disturbances. Also, the system should be able to respond to maintain its functionality above acceptable level when receiving damages from the disturbances, and in case of it fails to do so, it should be able to respond to recover or bring the system functionality back above acceptable level.

It was found out that functionality, responsiveness (all the responses or actions taken before, during and after a disturbance) and disturbance are the three main elements often included in many resilience definitions. Vulnerability is another element which is often mentioned as well when defining resilience. No system is perfect and vulnerability exists in all systems and vulnerability of a system can be considered as the opposite to the responsiveness of a system which can harm the resilience of the system. Eventually, it was decided that vulnerability is also included as an important element in the definition of resilience (*Figure 29(c)*). By understanding that the main concern of the resilience of a system is the functionality of the system in any situation or any disturbances, and that the system functionality is determined by and dependent on its own responsiveness and vulnerability which are opposing to each other, the resilience for this study context is defined as shown in *Figure 29(d).* This resilience definition can function as a definition framework so that it can be used to define resilience of a certain system for a more specific situation. The definition of energy resilience of this study is defined based on this definition framework.

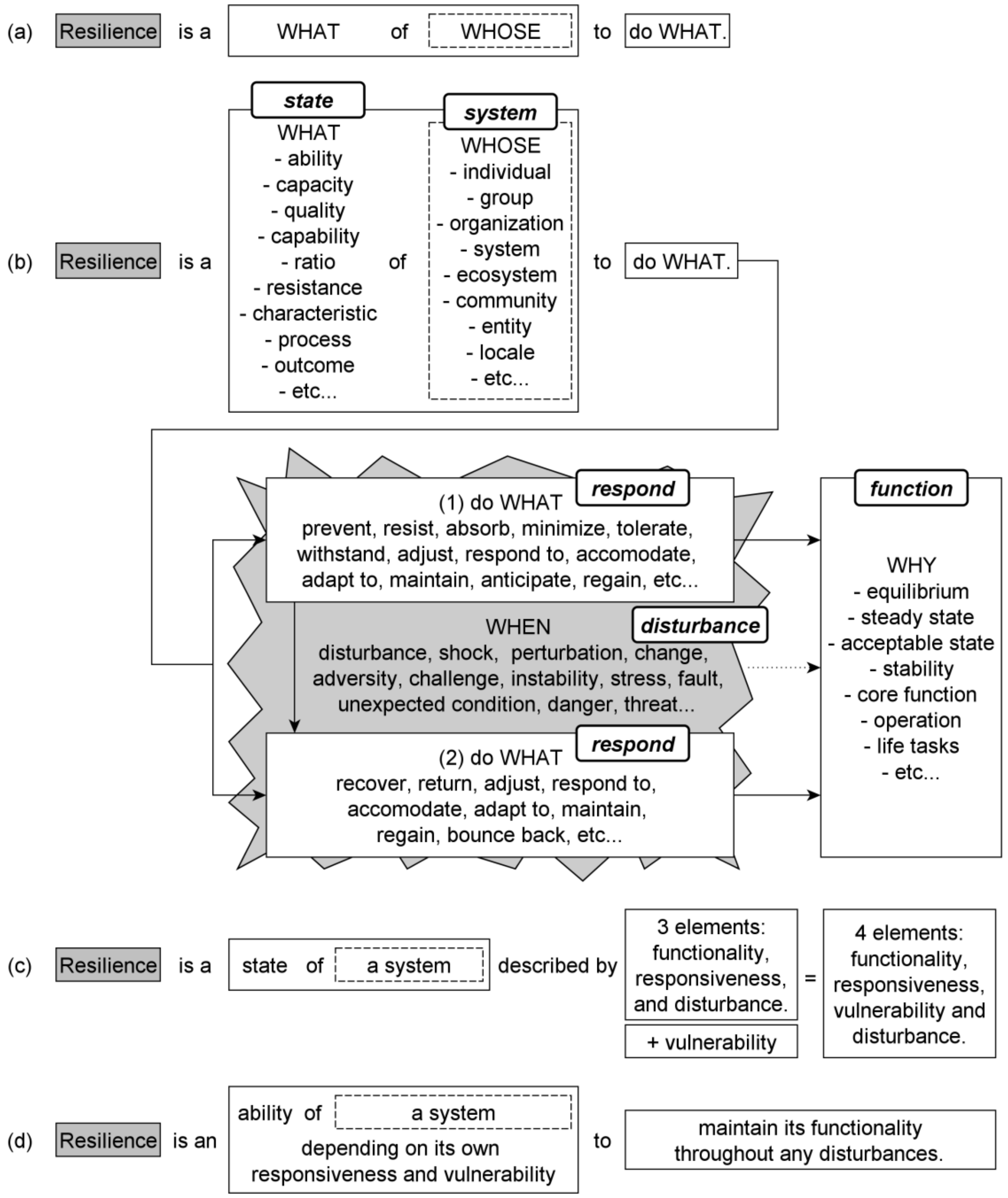


Figure 29 (a) Quasi-semantical analysis of resilience definition, (b) Expansion of general structure of resilience definition, (c) Main elements in a resilience definition, and (d) Definition of resilience for this study context

3.3.1 Distinguishing resilience

How is the definition of resilience in this study different from the others (*Appendix 6* and *Appendix 7*)? As there are many differences and similarities between this and others' resilience definitions, it is easier and more straightforward to list out the distinctions the definition of this study has over most of the other definitions.

- Emphasizing the functionality of a system as the main indicator of resilience.
- Emphasizing the existence of positive (responsiveness) and negative (vulnerability) elements within a system and its environment which can affect its resilience.

Also, it is necessary to distinguish resilience from other concepts or properties which have very similar meaning to the term of resilience, for example, reliability, sustainability, flexibility and others. As those properties including resilience usually describe the property of a system, they all have overlapping meaning and usage to each other under different context. In this study, resilience is distinguished by describing the performance, behavior and changes of a system throughout an occurrence of disturbance. Figure 30 shows the timeline chart used to distinguish resilience from reliability, protection, safety, stability, robustness, resistance and recovery. The timeline chart is made up by three phases of disturbance: before, during and after a disturbance. The conditions of each phase are described by the statuses of disturbance, operation and functionality of a system.

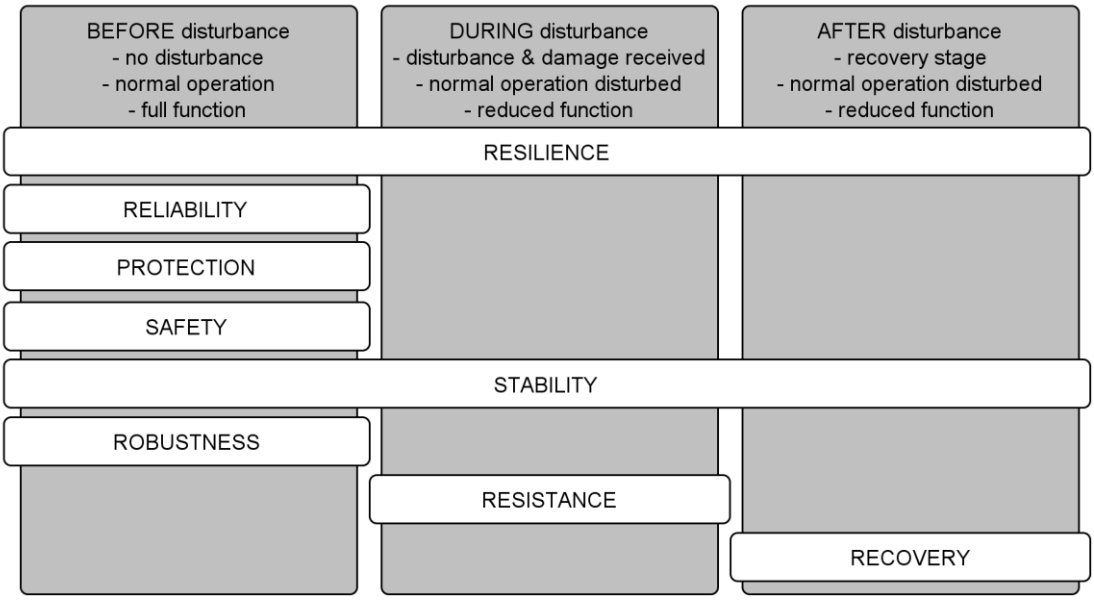


Figure 30 Distinguishing resilience from other similar concepts and properties

Resilience plays an important role during all the three phases. A resilient system should be able to detect and avoid disturbances from happening, prevent disturbances from getting worse if they cannot be avoided, and recover the disturbed system back to its original and normal condition (Jackson, 2010). Reliability implies that the system does not fail in a certain time period (Bonnefoi, 1990). Protection covers all risks and thus usually involves high cost (Hoffman & Nilchiani, 2008). Safety emphasizes the importance of avoiding unwanted outcomes (losses, harms, incidents, accidents) (Hollnagel, 2010). Reliability, protection and safety of a system are considered failed when the system starts to receive damages from disturbances. Stability spans over all three phases like resilience but one significant difference is that the stability property does not emphasize on recovery speed. Robustness is associated with smaller disturbances whereas the resilience is concerned with severe disturbances (Gao, 2010). A system loses its robustness when its physical structure is damaged or the consequences of structural failure are not disproportional to the effect causing the failure (CEN, 1994). Resistance of a system does not manifest until a disturbance arises. Resistance property of a system minimizes the adverse impacts from the disturbance but it does not consider recovery. The recovery property literally only covers the recovery stage.

3.4 Concept framework

The concept framework of the resilience assessment methodology defines the meaning of resilience in this study context (Please refer to *3.3 Definition of resilience*) and explains how characteristics and mechanism of a system in its own operating environment gains or loses the property of resilience. First of all, it is important to understand the systems thinking used in this study. Reductionism is applied in this study that a system is equal to the sum of its parts or components (Please refer to *1.6.1 Concept used for systems thinking*). *Figure 31* shows the graphical representation of the concept framework and the emergence of resilience in a system.

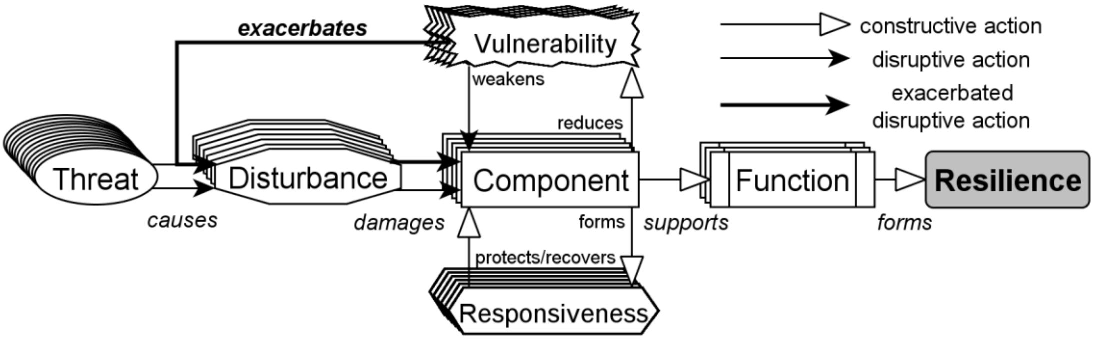


Figure 31 Concept framework and emergence of resilience in a system

This concept framework also represents the integration of the resilience definition of this study, concept of reductionism, and the idea of how disturbances cause impacts to a system and its functionality (*Figure 20*, page *36*). Under the concept of reductionism, a system consists of many components and the components interact with and interdepend on each other to support or perform the target functions of the system. The overall system functionality decides the level of system resilience. There are many external and internal threats which may turn into disturbances and the disturbances can eventually reduce the system resilience. When a component is damaged due to any disturbance, the damaged component cannot fully support its function and that results in reduction of system resilience. As a result, resilience of a system is dependent on the vulnerability and responsiveness of its components. Vulnerability exacerbates the impact of disturbances whereas the responsiveness protects and recovers the system.

3.5 Indicator selection framework

The methodology proposed by Maclaren is adopted as the indicator selection framework of this study (*Figure 32*). Only a brief of each step is explained below and further information should refer to Maclaren's comprehensive paper.

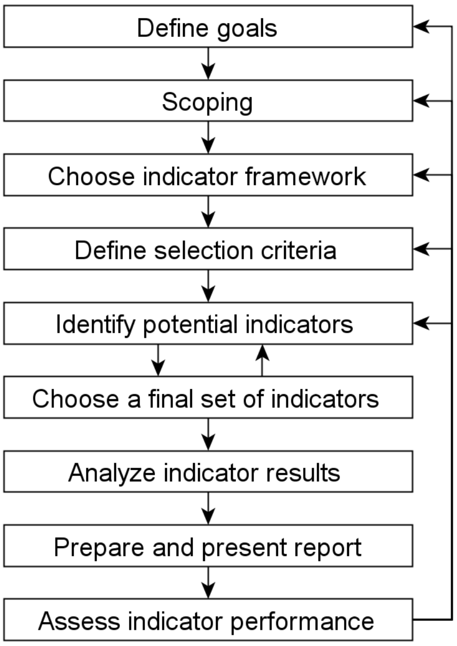


Figure 32 Indicator selection framework (Maclaren, 2007)

Define goals

The goals, objectives or purposes of the assessment must be defined clearly in order to select appropriate indicators for it in the later steps.

Scoping

Scoping requires the specification of target audience, associated purpose, estimated number of indicators, temporal and spatial bounding of the assessment.

Choose indicator framework

Five general frameworks can be used to develop sustainability indicators (which also applicable to resilience) and they are the domain-based, goal-based, sectoral, issue-based and casual frameworks. Hybrid framework is also often used.

Define selection criteria

The selection criteria are general and have no relevance to the properties of resilience in the case of this study or any assessment target. These selection criteria are significant determinants of the viability and validity of indicators. The following is frequently used selection criteria.

- ***Representativeness, usefulness, and relevance***: representative, understandable by targeted users, comparable with results or indicators from past studies or other regions, relevant to the needs and objectives of the assessment, responsive to change.
- ***Scientific validity and analytic soundness***: supported by established scientific and theoretical principles, able to be mathematically modeled, unambiguous.
- ***Measurability and feasibility***: data which are available, frequently updated, accurate and accessible, affordable and cost-effective to collect and use.

Identify potential indicators, choose a final set of indicators, analyze indicator results, prepare and present report and assess indicator performance

These refining steps are followed and repeated until the final set of indicators are deemed as suitable for use in the assessment.

3.6 Analysis framework

Assessment tool used for decision making usually also involves assessment subjects which are merely at the stage of planning and designing. When data is not available, modeling and simulation are needed to simulate data for assessment. There are many modeling methods and in the case of energy system, computational modeling and simulation are frequently used because it is usually more economical, efficient and reasonable choice especially when disturbance cannot be easily modeled or created in real life. It is widely agreed that no model will ever behave the same way as the real subject. As with any modeling and simulation methods, simplification has to be made for various factors such as cost, time and modeling objectives. In addition, usually analysis methods are applied in the simulation process which vary with different fields of study.

Chapter 4

Development of assessment model

Based on the assessment methodology proposed in the previous chapter, this chapter explains the process of developing an assessment model of energy resilience of communities based on bottom-up approach. The developed assessment model will be applied in case study later to study how energy resilience of a community is affected by demand response capacity.

4.1 Introduction of assessment model

Resilience is an important property in the built environment when there are numerous threats and uncertainties around to cause disturbances and disorders to human daily activities. This study aims to propose an assessment methodology to assess energy resilience of a community based on bottom-up approach. The objective of developing this assessment model is to propose assessment indicators and demonstrate how the assessment can be made. Important information regarding the development of the assessment model is explained in the following sections.

4.1.1 Objective of assessment

The assessment model is used to demonstrate how the usefulness of the proposed assessment methodology and assess the effect of demand response (DR) capacity on energy resilience of a town-level community. The assessment results can be used and referred to find out what a community system is lacking or underperformed, and then to make decision on how and what to do to improve energy resilience of communities so that interruption to demand-side users' activities can be minimized and power utility companies can maintain stable power supply. Moreover, the assessment model can provide useful and understandable information to target audience including policymakers, urban planners and also community members who are not professionals especially in the field of electrical and power engineering.

4.1.2 Key stakeholders

Generally, there are three key stakeholders playing important roles in deciding the energy resilience of communities and they are the community members, power utility companies and policymakers or town planners.

A community member can be a direct beneficiary and also a victim of any decisions made to the community which result in either better or worse outcomes. Under incentive-based DR program, demand of a community member is considered as a virtual source of power supply which can be used to achieve power balance that the community member can be seen as involving in power operation more than ever than just a plain power consumer. The decision of each community member on whether to fulfill the request of DR or not can collectively affect the energy resilience of their community. The installation of distributed generation such as solar panels by community members can also contribute to the power balance of the community.

Power utility companies are very influential key stakeholders in this assessment condition because after all a smart grid system nowadays and in the near future is expected to still have to rely on the bulk power source supplied by them. A power utility company has the responsibility to provide uninterrupted service of power supply to its customers but the increasing power demand and sometimes unpredictable events and disturbances have been difficult challenges to fulfill the responsibility. Building more power plants will take a-few-year of time to complete and increasing capacity of existing power plants sometimes are not economically feasible. Under the smart grid system, demand-side energy management including DR is a means to reduce the burden and solve the problems of insufficient power supply of utilities companies.

The third key stakeholder is the policymakers and town planners who are usually from the government sector and have the responsibility to create policies and make plans to benefit the community members, which in this case, to create resilient community. Their role especially the policymakers is also very influential in the way that they can make policy to influence the community members and power utility companies. For example, they can increase the feed-in tariff of renewable energy to boost more adoption of solar panels or wind turbines in the demand-side community, and they can amend the requirement of carbon reduction to control the power generation operation from the supply side. In the case of town planners, their decisions on the composition of new towns with buildings of different functions (with different demand patterns) will determine the fundamental resilience property of the new towns.

Each key stakeholder has their own influences, responsibilities and needs in the mission of creating resilience capacity in communities and therefore the selection of assessment indicators is important so that their respective interests and needs are reflected and covered in the indicators themselves.

4.1.3 Scale and system boundary of assessment

The assessment target in this study is communities at town level (*Figure 33*). The author has chosen town-level scale of community because a town community has the optimum community scale to form energy-autonomous community or a town-level microgrid. Sharing energy is a backbone behind the concept of a microgrid and it can be done from as little as two buildings. However, if the scale is too small (neighborhood level) then the result may not be optimum; when too large (city level) then it may be too difficult to manage. A town is large enough to have substantial amounts of different building types (residential, office, commercial buildings, etc.) to achieve a more stable (less fluctuating) aggregated power demand of the whole town. In addition, an average town with three to five villages in urban area in Japan matches with the scale of a substation grid system. When other community scales are also feasible, this study has chosen town-level as the community scale for the reasons stated above.

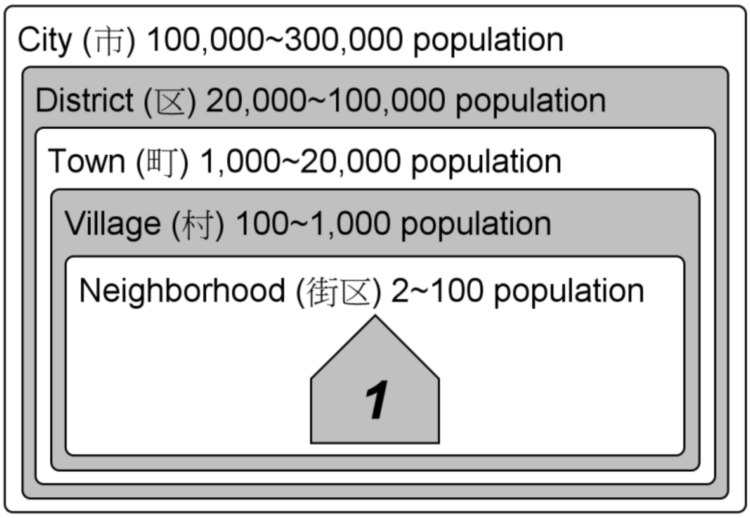


Figure 33 Community hierarchy and population in Japan urban area (adapted from (Doxiadis, 1968))

In this study, a town-level community is treated as a system and villages and neighborhoods under it are components and subcomponents of the community. The assessment is based on daily power operation taking place within a community and is limited on power generation and consumption of buildings (houses, offices, factories, hotel, etc. including their distributed generation). However, the system boundary of the assessment not only covers a community itself, but also considering the bulk power supply from the supply side (centralized power plants) connecting to the power substation of the community.

4.1.4 Data and threshold of assessment

The assessment data is primarily based on the daily power operation and the operation condition of the power components. Main discussion of assessment data used to measure the assessment indicators is given in *4.5 Indicator component*. Every assessment tool requires a threshold or benchmark value to evaluate and compare the performance of an assessed subject. There are several indicators proposed in this study and there are a few methods to decide the thresholds for those indicators. In case of well-established indicators, we can refer to existing references and standards, or any international or national targets or goals related to the indicators. For example, if energy saving is an indicator, we can use the national target of energy saving as the threshold. For new indicators without existing references, their benchmark values can be decided through the discussion of key stakeholders, surveys and questionnaires. All indicator thresholds should be revised based on the feedback from every stakeholder to suit changing needs and requirement.

The threshold of an indicator is used to decide if the indicator is performing well or underperforming. The threshold values used in the case study later are arbitrary and only for demonstration purpose. In reality, no matter if an indicator is well established or new, the threshold performance value for each indicator should be objectively decided by all the key stakeholders of a community system. They should sit down together if possible, or else opinions from all stakeholders including the users should be collected and reflected in the final selection of indicator thresholds that are agreed by all stakeholders. The appropriateness of the selected indicators and threshold values should be reviewed and revised to meet the changing conditions from time to time.

4.2 Structure of assessment model

Figure 34 below shows the structure of resilience assessment model developed in this study which follows the similar structure of the resilience assessment methodology. The core of this assessment model consists of three components: concept, indicator and analysis components. The concept component explains and discusses about the definition of energy resilience and its attributes, and also how characteristics and mechanism of a community system in its own operating environment gains or loses the property of resilience in the aspect of energy performance. The indicator component describes the functionality and attribute (responsiveness and vulnerability) indicators of the assessment model. The analysis components explains the processes of modeling and simulation of daily power operation (the source of assessment data) and the optimization method and power flow analysis applied to complement the analysis processes.

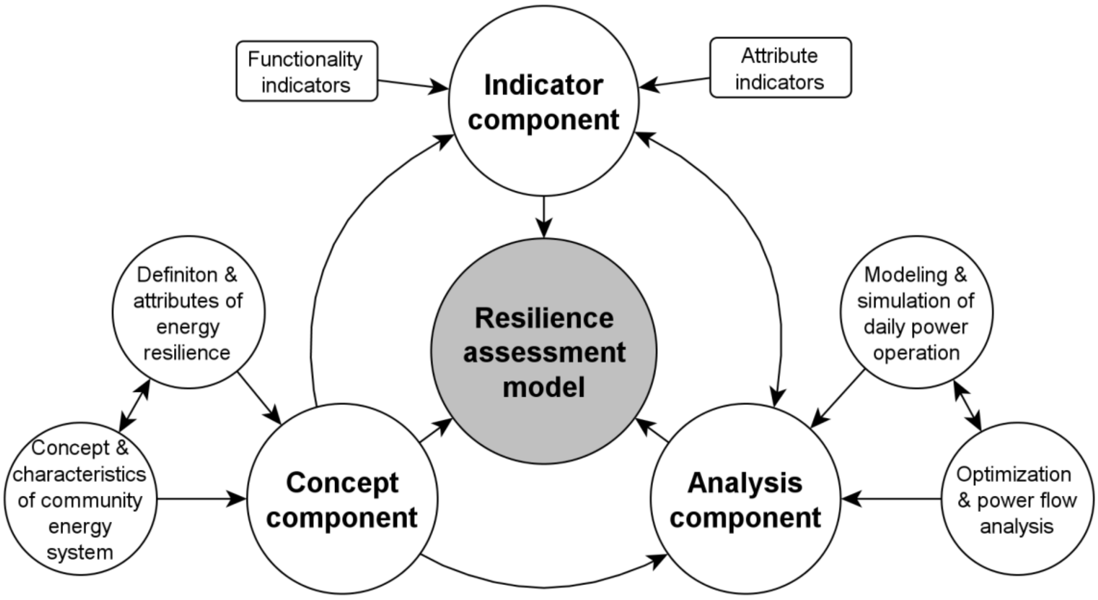


Figure 34 Structure of resilience assessment model

4.3 Quick view of assessment model

This section aims to give a quick view and brief explanation on how the developed assessment model works (*Figure 35*). The assessment data is based on the daily power operation of a community. The analysis model describes the modeling of community system and its power components (generation, network and consumption components) and the simulation of daily power operation. The analysis results are used in the assessment model to demonstrate the proposed assessment methodology. In the analysis model, there are generation, consumption and reserve units on both supply and demand sides. In the case of the supply side, the power generation units are various types of centralized power plants, large-scale mega solar farm, wind turbines and so on, the power consumption units are the power plants themselves that consume power to run their operations, and the power reserve units include the pumped-storage hydroelectric generation, spinning, non-spinning and supplementary reserve generation. On the other hand, in case of the demand side, the power generation units are distributed generations such as on-site generators, solar panels and wind turbines, the power consumption units are various types of buildings in a community, and the power reserve units are the any energy storage in a community. Daily power operation starting from forecasting to the end of the daily power operation will be simulated on hourly time scale (Please refer to *4.6 Analysis component*). Disturbances will be included in the analysis as destabilizing factors to daily power operation. As mentioned as one of the scopes of this study in *1.4 Scope of research*, while this study does not specify any limit to the kind of disturbances that can happen to a community system, however, the effects and damages caused by the disturbances to system performance are limited to those that are small-scale and short-term. As a result, disturbances in this study can be defined as any destabilizing factors that can cause small-scale and short-term difficulties to daily power operation of a community system to achieve power balance.

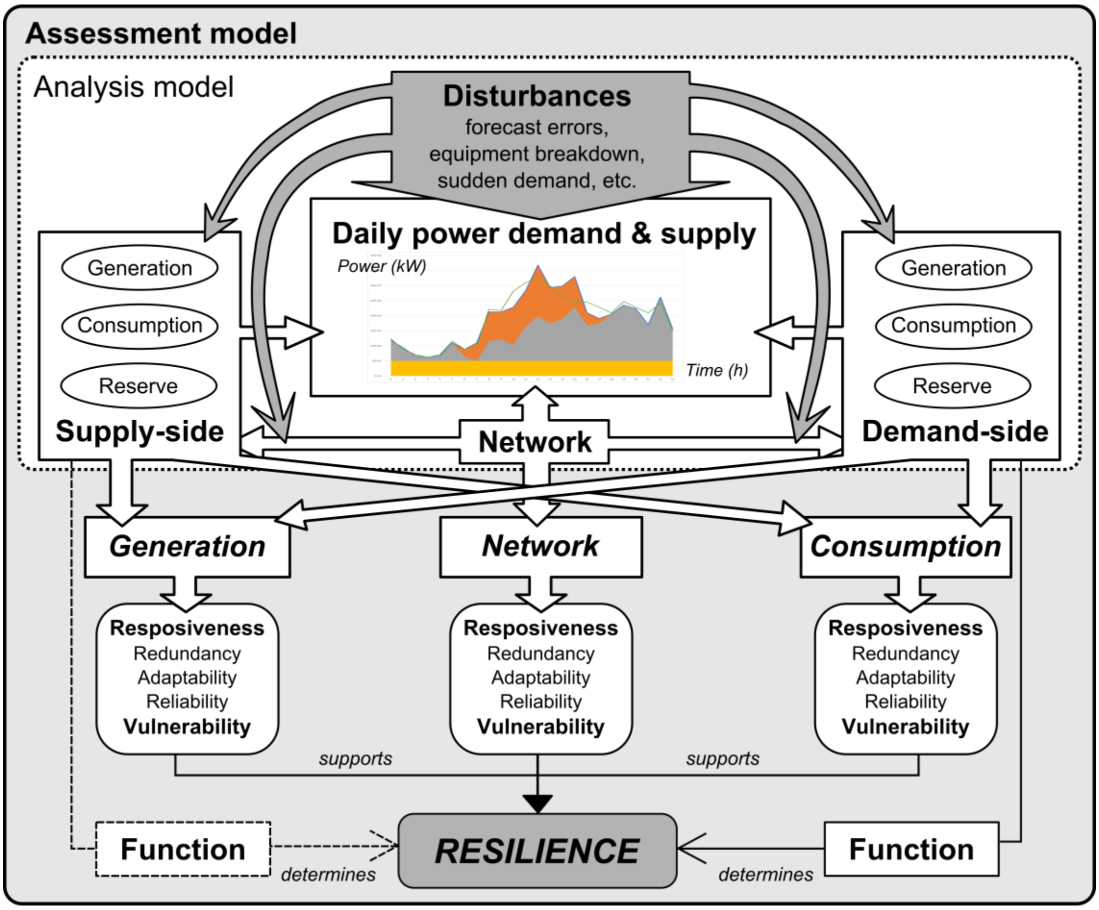


Figure 35 Bottom-up assessment

After the analysis is finished, analysis results of power components from supply and demand sides will be classified into three groups according to the nature of their roles in a power operation: generation, network and consumption components. It is important to note that when generation and network components are each representing power components that provide power supply and deliver power, the consumption component here is used to represent not only the conventional power demand but also the DR capacity (the power demand that users will *potentially* reduce when requested by the power utility company). Each type of power component will be assessed for their performance (responsiveness and vulnerability) indicators by using the analysis result and other additional data. Another performance indicators called as functionality indicators are assessed also based on the analysis result to represent the overall system performance. The functionality indicators will decide if a community system is resilient or not whereas the other performance indicators are supporting indicators which must be taken into account (Please refer to *4.5 Indicator component*).

The assessment results should be able to guide and facilitate the stakeholders in decision-making process.

4.4 Concept component

Resilience in this study context is defined as the ability of a system depending on its own responsiveness and vulnerability to maintain its system functionality throughout any disturbances. Resilience is a broad concept covering multiple disciplines but this study is only focused on the aspect of energy performance. Corresponding to that purpose, the resilience in this context is specified as energy resilience. Also based on the definition framework in *3.3 Definition of resilience*, energy resilience of a community is defined as follows. The community in the definition also includes all the relevant energy systems connecting to itself.

> *The ability of a community depending on its own responsiveness and vulnerability to maintain its energy-dependent community functionality throughout any disturbances.*

The main difference is that the functionality is now more specific to community functionalities that are dependent on energy performance including power balance of the community system. *Figure 36* shows the graphical representation of the concept component of the resilience assessment model. Different building types represent the power generation and consumption components of a community system and they are connected by the power network component. The power components interact with each other to support community functionality. The functionality performance in disturbance scenario will determine the resilience performance of the community system. Disturbances considered in this study are any destabilizing factors that can cause small-scale and short-term difficulties to daily power operation of a community system to achieve power balance. The ability or capability of the components to support system functionality is dependent on the responsiveness and vulnerability of the components themselves. In other words, responsiveness and vulnerability of the components are the supporting performance of energy resilience. In this study, responsiveness and vulnerability are treated as the resilience attributes and responsiveness is further broken into redundancy, adaptability and reliability. These attributes are selected because they are among the top and most representative attributes of resilience found in many existing literature. Further explanation of the resilience attributes are given in the following.

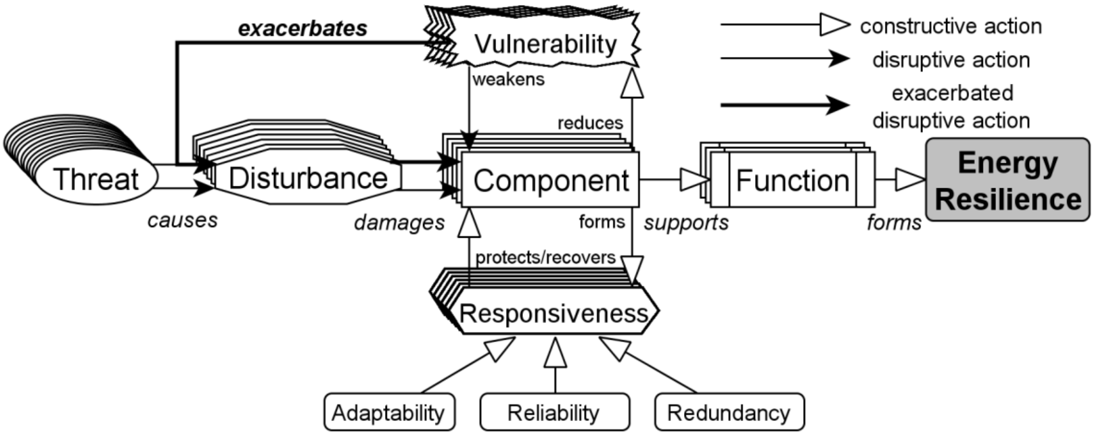


Figure 36 Concept component

4.4.1 Definition of redundancy

Some studies considered redundancy as a significant attribute of resilience (Gao, 2010) (Hollnagel, et al., 2006) (Marshall & Chapman, 2002). According to those studies, redundancy of a system is achieved through either partial or total provision or duplication of critical components of a system so that level of functionality can be maintained in any events of failures. Apart from that, redundancy also can come in the form of alternative means to achieve the same functionality. In this study, energy resilience of a community is assessed based on daily power operation and redundancy is defined as follows.

> *Redundancy is remaining and unused capacity of a component or system which can be used to achieve power balance.*

In the case of a power generation component in a community system, redundancy can be the balance of maximum generation capacity minus generation capacity in operation. Redundancy of a power consumption component can be the balance of maximum DR capacity minus DR capacity in operation. In the case of a network component connecting supply and demand sides, redundancy can be the balance of maximum allowable power capacity minus power capacity flowing through the network component during operation. These are the general methods to define redundancy indicator of each type of component, please refer to *4.5.2 Redundancy* *indicator* for more coverage including modified methods to define redundancy indicators for certain components.

4.4.2 Definition of adaptability

Plenty of literature discussed about the definition of adaptability (Burton, et al., 2001) (Hooker, n.d.) (Olmos, 2001) and its role in a resilient system (Gallopin, 2006). A comprehensive definition by Burton and others considered adaptability as an adjustment in natural or human systems in response to experienced or future climatic conditions or their effects or impacts—which may be beneficial or adverse. Also, key words such as timeliness, spontaneous and planned indicate that adaptability of a subject is dependent on the time or rate of its adjustment action. Some studies regarding energy systems suggested that a diversified energy system is more resilient and adaptable to disturbances (Lo, 2011) and adaptability is equal to flexibility and dependent on diversity (Stirling, 1994). In this study, energy resilience of a community is assessed based on daily power operation and adaptability is defined as follows.

> *Adaptability is remaining and unused capacity of a component or system which can be used almost instantly when it is needed to achieve power balance.*

In this study, adaptability of a subject is an attribute extended from its redundancy which emphasizes on the time or rate of its adjustment action. If redundancy is about the quantity of capacity which can be used to achieve power balance, then adaptability is about the quality of those capacity in the aspect of response time. In the case of a power generation component in a community system, adaptability can be the dispatchable generation capacity of the maximum redundant generation capacity. Adaptability of a power consumption component can be the dispatchable DR capacity of the remaining or redundant DR capacity. In the case of network component, adaptability can be the ratio of the amount of remaining and unused bypass power lines over the total amount of available bypass power lines. These are the general methods to define adaptability indicator of each type of component, please refer to *4.5.3 Adaptability indicator* for more coverage including modified methods to define adaptability indicators for certain components.

4.4.3 Definition of reliability

Reliability of energy systems is a very well-established study. In this study, energy resilience of a community is assessed based on daily power operation and reliability definition of the IEEE (The Institute of Electrical and Electronics Engineers (IEEE), 1998, p. 139) is modified and then adopted.

> *Reliability indicates the ability of a component to continue to perform its intended function to achieve power balance.*

Also according to IEEE, some meaningful reliability measures especially for power distribution systems are listed below.

- Unavailability
- Availability
- Frequency of system failure
- Expected failure duration

Reliability is difficult and time-consuming to measure because it is a statistical number derived from historical experience and short-term test of a component of interest (Marshall & Chapman, 2002). Marshall and other studies also argued about whether resilience and availability are the same or different. In this study, availability is considered as one of the measures of reliability and it can be used as the reliability indicators of power generation, network and consumption components in a community system (More information regarding reliability indicators, please refer to *4.5.4 Reliability indicator*).

4.4.4 Definition of vulnerability

Vulnerability is also another well-studied subject in many fields of study especially risk management. The interpretation of vulnerability and its effects on a system is described in *Figure 20* (Page *36*). A lot of vulnerability definitions are available (Christiansson, 2004) (Pelling, 2003) (Bankoff, et al., 2004) and among them the definition proposed by Bankoff is modified and then adopted in this study.

> *Vulnerability is an internal risk factor that is mathematically expressed as the feasibility that the exposed component may be affected by the phenomenon that characterizes the hazard to disturb power balance.*

Vulnerability of a component can be assessed based on the probability of frequency of the component receiving damages from any disturbances and the criticality of impact the damaged component will cause to the system in the aspect of functionality (Montoya, 2010) (Department of Defense, 2000) (American Petroleum Institute, National Petrochemical & Refiners Association, 2004). In this study, the vulnerability indicator of each component is assessed by comparing its actual vulnerability index to its design or target value of vulnerability index (More information regarding vulnerability indicators, please refer to *4.5.5 Vulnerability indicator*).

4.5 Indicator component

The resilience definition of this study context contains four main elements (*Figure 29(c)*, page *48*) and among them, functionality, responsiveness and vulnerability are used as assessment indicators. These assessment indicators are based on the performance of a community system (including its power components) and are divided into functionality indicators and attributes indicators (*Figure 37*).

The functionality indicators represent the resilience performance of a community system and are assessed based on the overall system functionality. The attributes indicators consisting of indicators of responsiveness (redundancy, adaptability and reliability) and vulnerability represent supporting performance indicators of energy resilience and are assessed based on the performances of power components (generation, network and consumption components). The supporting performance indicators are playing significant roles in the assessment methodology and the significance can be explained by the analogy of a company assessed for its business profit. A company can make profit and yet possesses a little assets and many liabilities. The information of assets and liabilities are good indicators to show the current operating condition of the company and provide foresight about the chances of the company to continue making profit or not. The same goes to supporting attribute indicators which can be good indicators to provide foresight about the future resilience of a community system.

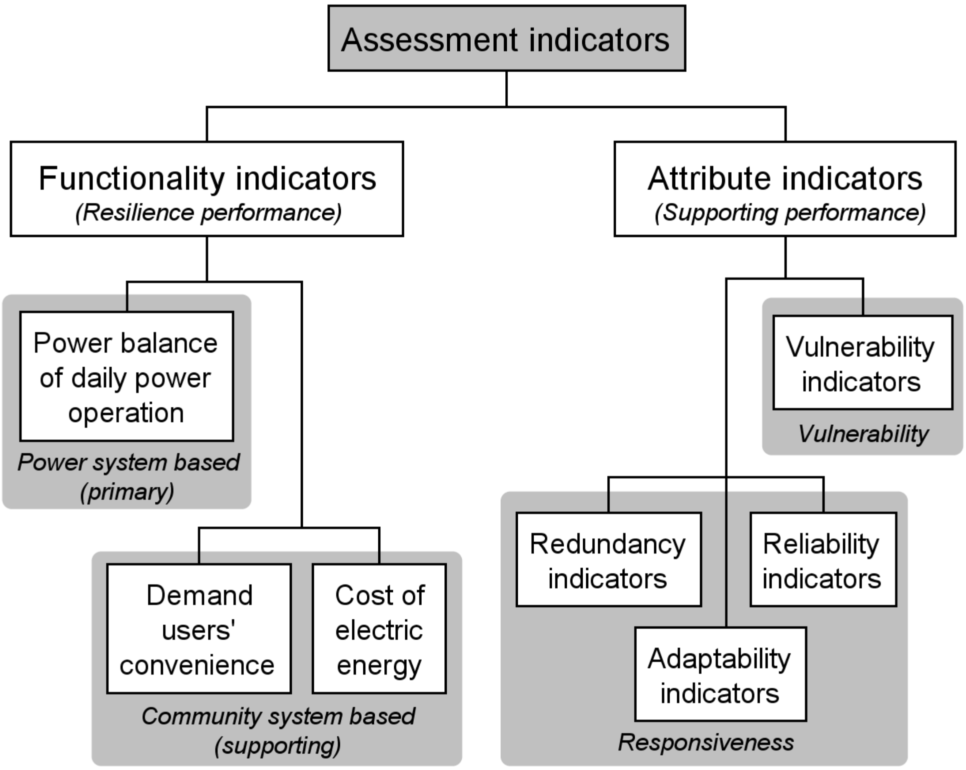


Figure 37 Categorization of assessment indicators

Functionality indicators can be any highly ranked functions, purposes or goals of a community system in the aspect of energy performance and those functions can be based on either supply-side or demand-side interests exclusively, or mutual interests. As the purpose of this study is to assess effect of DR capacity on energy resilience, the most significant functionality indicator for this purpose is the power balance of daily power operation that it indicates if DR can help in achieving power balance or not in various disturbance scenarios. However, a resilient community system must also support human activities within the community which are dependent on the power balance status. Even if a community system can achieve power balance but if significant community activities are compromised below acceptable levels, the community system is deemed as failed and not resilient. Power balance is a resilience performance indicator more relevant to supply side but it is depended by activities or functions of a community system which in the point of view of community users or the demand-side users are what define the resilience performance of the community.

On the other hand, there are numerous attributes that can support and describe the resilience property but only four attributes (redundancy, adaptability, reliability and vulnerability) have been selected among the top and most representative attributes of resilience found in many existing literature. Indicators of those resilience attributes are selected based on the selection criteria as mentioned in *3.5 Indicator selection framework* and the consideration of the objective of this assessment model. Generally, attribute indicators are selected by adapting or directly applying well-established indicators of the attributes. Each power component is assigned with its own set of attributes indicators, however, the principle of deriving mathematical expression of the indicators is the same across all the power components for the same attribute indicator.

Most of the assessment indicators use assessment data obtained from daily power operation, for example the power capacity of generation and consumption, DR capacity and power flow in power lines. Some indicators such as reliability and vulnerability indicators depend the operation condition and information of power components as assessment data, for example, mean time between failures and participation rate of DR.

4.5.1 Functionality indicator

Functionality indicators are selected from functions of a community system. A function can be an interest of supply side, demand side or both sides and is usually used as an objective function for the optimization of daily power operation. For an instance, a common function of any energy system is to generate energy at the lowest cost and this function is used as the objective function to optimize the operation of the energy system so that the cost of energy generation is minimum. Different systems have different priority for its functions and it is usually decided based on the objective of a system.

The primary reason of considering using DR program in a smart grid system is to provide extra power resources to achieve power balance of the power operation. Power balance is one and the most significant function of a community system because community functions or activities depending on power supply will be severely affected if a power balance fails that power outage or blackout happens. As a result, power balance is selected as the first and primary functionality indicator. General definition of power balance is used that it is *a stable condition when power supply meets the requirement of power demand of a community system*. Whether power balance can be achieved or not depends on the performances of the power components of a community system including the available DR capacity. Computational method will be used in analysis model to study daily power operation of communities (*Figure 42*). Power balance is calculated from the analysis and it is a binary indicator that shows if a daily power operation manages or fails to achieve power balance.

$$FT1 = Power\ balance\ of\ daily\ power\ operation$$

- $FT1$: Power balance of daily power operation (primary functionality indicator).

Power balance is only part of many community functions but certainly a primary one that is directly linked to the performance of a DR program. The performance of other significant community functions which are dependent on power balance should also be taken into account as part of the resilience performance of a community system. There are many possible candidates of significant community functions. Demand users' convenience is selected as a supporting functionality indicator because community members are the sources of DR capacity and it is important that users' convenience can be maintained above certain minimum level when there are disturbances happening to their community. Demand users' convenience is defined as *the demand users' freedom to consume electric energy to achieve their activities during the whole daily power operation*. Users' convenience here means power consumption that can affect users' quality of life such as productivity, comfort and health. The indicator value of demand users' convenience ranges from 0 to 1. Maximum demand users' convenience is 1 when there is full freedom or no restriction on the power consumption whereas it is 0 when the demand users commit maximum DR capacity. Based on the given definition, demand users' convenience is mathematically expressed as follows. *Figure 38* can be referred for better understanding of this definition.

$$FT2 = \frac{actual\ demand}{unrestricted\ demand}$$

$$= \frac{\sum_{t=0}^{23} dm_{ct}}{\sum_{t=0}^{23} DM_{ct}} \qquad \text{(Eq. 1)}$$

$$= \frac{\sum_{t=0}^{23} dm_{ct}}{\sum_{t=0}^{23}(dm_{ct} + dr_{ct})}$$

- $FT2$: Demand users' convenience (functionality indicator).
- dm_{ct}: Actual demand of consumption component c at time t.
- DM_{ct}: Unrestricted demand of consumption component c at time t.
- dr_{ct}: Demand response contributed by consumption component c at time t.
- c: Consumption component unit.
- t: Time unit in hour.

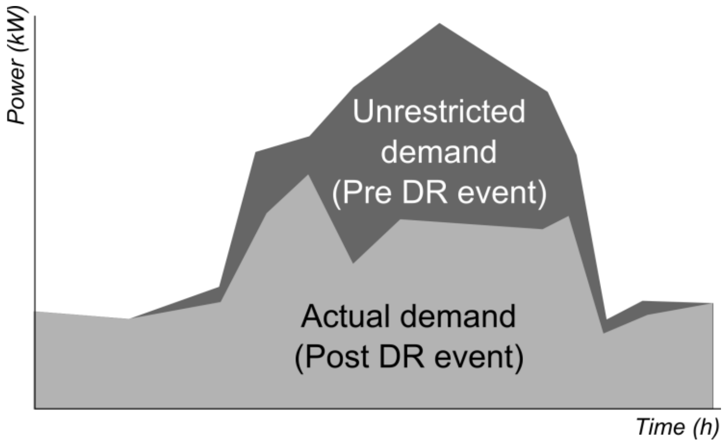


Figure 38 Illustration of different community demands

Cost of electric energy is selected as the second function because cost has always been the main concerns for both sides. It is defined as *the average cost of 1kWh electric energy produced by various types of generators including demand response capacity*. Power utility companies want to generate electric energy at the lowest possible cost and demand-side users want to enjoy the lowest possible price for each kWh of the electric energy. Therefore, cost of electric energy is a significant mutual interest. The indicator value of cost of electric energy is a positive value which should be kept as low as possible. This indicator can be mathematically expressed as follows.

$$FT3 = \frac{total\ cost\ to\ achieve\ power\ balance}{total\ power\ supply}$$

$$= \frac{\sum_{t=0}^{23}\sum_{g=1}^{Ng} cs_{gt} + \sum_{t=0}^{23}\sum_{c=1}^{Nc} cs_{ct}}{\sum_{t=0}^{23}\sum_{g=1}^{Ng} sp_{gt}} \quad \text{(Eq. 2)}$$

- $FT3$: Cost of electric energy in unit of \$/kWh (functionality indicator).
- cs_{gt}: Cost of electric energy supplied by generation component g at time t.
- cs_{ct}: Cost of demand response committed by consumption component c at time t.
- sp_{gt}: Power supply of generation component g at time t.
- g: Generation component unit.
- N_g: Total number of generation component units.
- N_c: Total number of consumption component units.
- c, t: Please refer to (Eq. 1).

Performances of functionality indicators determine whether a community system is energy-resilient or not. A threshold or benchmark value is decided for each functionality indicator through the discussion among the key stakeholders, for example, minimum value of demand-side users' convenience, highest acceptable cost of electric energy and minimum target of energy conservation. Energy resilience of a community system is dependent on the degree of the functionality indicators of the assessment results in fulfilling their respective target value.

As an additional note, daily power operation in this study is optimized with minimizing the cost of electric energy. However, actually conflicts exist among the three functions. In order to increase demand users' convenience the users are supposed to use electric energy to support their activities without restriction, however, this situation will limit or even decrease energy conservation. This kind of conflict always exists in real-life problems and tradeoff needs to be made. (More discussion about conflicts among indicators, please refer to *4.6.1.3 Objective function*).

4.5.2 Redundancy indicator

Redundancy is generally defined as the remaining and unused capacity of a component or system which can be used to achieve power balance (Please refer to *4.4.1 Definition of redundancy*). Redundancy is one of the attribute indicators and each power component, namely the generation, network and consumption components, is assigned with its own redundancy indicator. Each power component is assigned with its own redundancy indicator, however, the principle of deriving mathematical expression of the indicators is the same across all the power components. It is important to note that when generation and network components are each representing power components that provide power supply and deliver power, the consumption component here is assessed based on its DR capacity (which can be seen as a virtual source of power supply).

Generally, redundancy of a power generation component in a community system, is the balance of maximum generation capacity minus generation capacity in operation. Redundancy of a power consumption component is the balance of maximum DR capacity minus DR capacity in operation. In the case of a network component, redundancy is the balance of maximum allowable power capacity minus power capacity flowing through the network component during operation. *Figure 39* illustrates the notion of redundancy used to derive mathematical expression for the redundancy indicator.

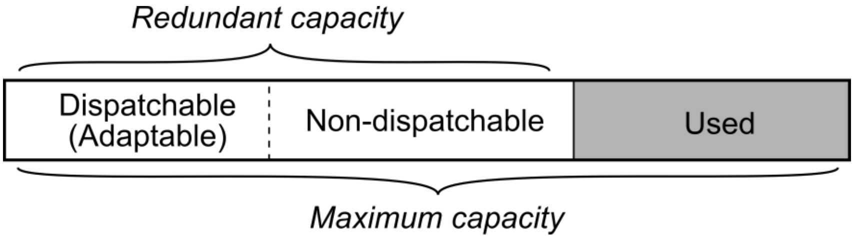


Figure 39 Principle behind definitions of redundancy and adaptability indicators

Generation component

The source of power supply comes from various types of generators with different characteristics and generation mechanism. In this study, generation sources are divided into stable, storage and intermittent types. Stable generations such as most of the fossil-fuel based generation (coal, natural gas, nuclear) and hydroelectric generation, they usually have a stable output of power generation which is why they are often used to supply most of the power demand. The indicator value ranges from 0 to 1 where maximum redundancy is represented by value 1. Redundancy indicator of a stable generation component unit is as follows.

$$rd_{gt} = \frac{remaining\ generation\ capacity}{maximum\ generation\ capacity} = \frac{gc_{gt} - sp_{gt}}{gc_{gt}} \quad \text{(Eq. 3)}$$

- rd_{gt}: Redundancy of generation component g at time t.
- gc_{gt}: Maximum generation capacity of generation component g at time t.
- sp_{gt}, g, t: Please refer to (Eq. 1) and (Eq. 2).

Storage-based generations in this study are those generation sources which usually serve the purpose of ancillary services such as battery storage and pumped-storage hydroelectric generation. They are usually highly responsive to change of power balance that they are discharged to achieve power balance and usually charged into its original state at the end of the daily power operation. The indicator value ranges from 0 to 1 where maximum redundancy is represented by value 1. Redundancy indicator of a storage-based generation component unit is as follows.

$$rd_{gt} = \frac{current\ storage\ capacity}{previous\ storage\ capacity} = \frac{gc_{g(t-1)} - sp_{gt}}{gc_{g(t-1)}} \quad \text{(Eq. 4)}$$

$$= \frac{gc_{gt}}{gc_{g(t-1)}}$$

- rd_{gt}: Redundancy of generation component g at time t.
- $gc_{g(t-1)}$: Previous energy storage capacity of generation component g at time $(t-1)$.
- sp_{gt}: Power supply discharged from energy storage of generation component g at time t.
- gc_{gt}: Current energy storage capacity of generation component g at time t.
- g, t: Please refer to (Eq. 1) and (Eq. 2).

The third type is intermittent generations which usually consists of renewable energy generations such as solar and wind power generations. As their power generations are completely dependent on the weather conditions, their generation outputs are unstable and intermittent. As a result, the maximum generation capacity of an intermittent generator is not certain and it is not appropriate to be based on upon considering the redundancy of the generator. Instead, forecasted power supply is used. In the case of actual power supply is more than the forecasted value, it is considered as redundant electric energy and otherwise, it is insufficiency of electric energy from the generation component. The indicator value ranges from 0 to 1 where maximum redundancy is represented by value 1 and insufficiency is value 0. Redundancy indicator of an intermittent generation component unit is as follows.

$$rd_{gt} = \frac{\begin{array}{c} difference\ between\ forecasted \\ and\ actual\ generation \end{array}}{maximum\ generation\ capacity} \qquad \text{(Eq. 5)}$$

$$= \frac{sp_{gt} - \overline{sp}_{gt}}{gc_{gt}}$$

- rd_{gt}: Redundancy of generation component g at time t.
- gc_{gt}: Maximum generation capacity of generation component g at time t.
- sp_{gt}: Actual power supply of generation component g at time t.
- $\overline{sp}_{gt}$: Forecasted power supply of generation component g at time t.
- g, t: Please refer to (Eq. 1) and (Eq. 2).

Consumption component

An effective way for a power-consumption component to help to maintain power balance is through DR program. It must be understood that only ongoing power demand is potential candidate of DR and demand-side users are usually given choices to participate DR event during normal condition of daily power operation. It is user-friendly to allow the users to choose the amount of power demand for the purpose of DR. The indicator value ranges from 0 to 1 where maximum redundancy is represented by value 1. Redundancy indicator of a consumption component unit is as follows.

$$rd_{ct} = \frac{remaining\ demand\ response\ capacity}{maximum\ demand\ response\ capacity} = \frac{drc_{ct} - dr_{ct}}{drc_{ct}} \tag{Eq. 6}$$

- rd_{ct}: Redundancy of consumption component c at time t.
- drc_{ct}: Maximum demand response capacity of consumption component c at time t.
- dr_{ct}, c, t: Please refer to (Eq. 1).

Network component

Power distribution lines help to deliver power supply from generation sources to the end-users. Due to thermal limit, each power line has a limit of allowable power flow capacity. In practice, one or more power lines or bypass lines connecting two or more service areas are installed to improve the reliability of the network system. The switch of a bypass line is usually opened (not connecting) in normal condition of power operation. A bypass line can be closed (connected) to deliver power supply to the connecting area if the existing power distribution lines of the connecting area have failed, and decrease the average power flow of each power lines during peak demand. The indicator value ranges from 0 to 1 where maximum redundancy is represented by value 1. Redundancy indicator of a network component unit is as follows.

$$rd_{nt} = \frac{remaining\ power\ flow\ capacity}{allowable\ power\ flow\ capacity} = \frac{pfc_{nt} - pf_{nt}}{pfc_{nt}} \tag{Eq. 7}$$

- rd_{nt}: Redundancy of network component n at time t.
- pfc_{nt}: Allowable power flow capacity of network component n at time t.
- pf_{nt}: Power flow of network component n at time t.
- n: Network component unit.
- t: Please refer to (Eq. 1).

4.5.3 Adaptability indicator

Adaptability is generally defined as the remaining and unused capacity of a power component which is dispatchable or can be used almost instantly when it is needed to achieve power balance (Please refer to *4.4.2 Definition of adaptability*). Similar to redundancy indicators, adaptability is assessed for each power component, namely the generation, network and consumption components. Each power component is assigned with its own adaptability indicator, however, the principle of deriving mathematical expression of the indicators is the same across all the power components. Adaptability indicator is extended from redundancy indicator (*Figure 39*) which aims to assess the dispatchability of power generation and DR capacity, and effective network components which can provide adjustment action to sustain power balance within a short time frame.

Generally, adaptability of a power generation component is the dispatchable generation capacity of the maximum redundant generation capacity. Adaptability of a power consumption component is the dispatchable DR capacity of the remaining or redundant DR capacity. In the case of network component, adaptability is the ratio of the number of unused bypass power lines over the total number of available bypass power lines. In real world, the dispatchability of each power component should be determined by professionals. *Table 14* and *Table 15* show the dispatchability of power generation and consumption components. In case of generation component, all generation types are assumed to have full dispatchability except for coal-based and nuclear-based generation which are relatively slow in modifying their generation outputs, and solar photovoltaic generation which is rated as non-dispatchable because of its intermittent nature depending on weather condition.

Table 14 Dispatchability of different generation types used in analysis

Generation type	Dispatchability
Pumped-storage hydroelectric	1.0
Oil	1.0
LNG+LPG	1.0
Coal	0.5
Nuclear	0.3
Hydroelectric	1.0
Storage-based generation	1.0
Solar photovoltaic generation	0.0

Table 15 Dispatchability of demand response capacity of different building types used in analysis

Building type	Dispatchability
Residential	1.0
Office	0.8
Commercial	0.8
Hotel	0.8
Factory	0.5
School	1.0
Hospital	0.2

In case of consumption component, the dispatchability of each building type is highly related to the significance of the building function. Residential buildings and schools are assumed to have full dispatchability to reduce their power demand whereas offices, commercial buildings and hotels are less dispatchable because these building types have to consume power to maintain their business activities. Factories are assigned with lower dispatchability because some factories require longer time or continuous power supply to keep the manufacturing or operation process to run safely. Hospitals have the lowest dispatchability because instantaneous power demand reduction is a risk to the building function which is related to human lives. In case of network component, dispatchability is decided by the available amount of bypass power lines in a community system.

Generation component

Generation sources used as spinning reserve for ancillary services are usually highly dispatchable generation such as natural gas and hydroelectric generations. Generations such as nuclear generation that require longer time (more than one or two hours) to ramp up or down the outputs are considered not dispatchable for ancillary services. This kind of generation can be used for long-term capacity adjustment such as meeting higher demand during summer, but not suitable as adaptable generation for use in daily power operation. Intermittent generations are usually considered not dispatchable due to the high uncertainty. The indicator value ranges from 0 to 1 where maximum adaptability is represented by value 1. Adaptability indicator of a generation component unit is as follows.

$$\begin{aligned} ad_{gt} &= dispatchable\ power\ generation\ capacity \\ &= dp_{gt} \cdot rd_{gt} \end{aligned} \qquad \text{(Eq. 8)}$$

- ad_{gt}: Adaptability of generation component g at time t.
- dp_{gt}: Dispatchability factor of generation component g at time t.

- rd_{gt}, g, t: Please refer to (Eq. 1), (Eq. 2), (Eq. 3), (Eq. 4) and (Eq. 5).

Consumption component

Only ongoing power demand is potential candidate of DR. Not all potential DR capacity is dispatchable because of demand-side users' convenience. A user may choose to have to refuse the request of DR because the user cannot suddenly stop ongoing activities and may require longer time to stop the activities. The indicator value ranges from 0 to 1 where maximum adaptability is represented by value 1. Adaptability indicator of a consumption component unit is as follows.

$$\begin{aligned} ad_{ct} &= dispatchable\ demand\ response\ capacity \\ &= dp_{ct} \cdot rd_{gt} \end{aligned} \tag{Eq. 9}$$

- ad_{ct}: Adaptability of consumption component c at time t.
- dp_{ct}: Dispatchability factor of consumption component c at time t.
- rd_{gt}, c, t: Please refer to (Eq. 1) and (Eq. 6).

Network component

A bypass line is a very adaptable network component. It can be switched on to instantly reduce the burden of other power lines and to behave as an alternative source of power supply when the existing power line of an area has failed. The indicator value ranges from 0 to 1 where maximum adaptability is represented by value 1. Adaptability indicator of a network component unit is as follows.

$$\begin{aligned} ad_{nt} &= \frac{remaining\ unused\ bypass\ power\ lines}{total\ number\ of\ bypass\ power\ lines} \\ &= \frac{bp_{nt}}{BP} \end{aligned} \tag{Eq. 10}$$

- ad_{nt}: Adaptability of network component at time t.
- bp_{nt}: Available number of bypass line of network component at time t.
- BP: Total number of bypass lines of network.
- n: Network component.
- t: Please refer to (Eq. 1).

4.5.4 Reliability indicator

Reliability is defined as the ability of a component to continue to perform its intended function to achieve power balance (Please refer to *4.4.3 Definition of reliability*). Each power component is assessed for its own reliability. Availability (Marshall & Chapman, 2002, p. 4) is used as the reliability indicator of generation and network components and participation rate in DR event for consumption component. These reliability indicators are statistically-based that their assessment data are collected and accumulated from the early stage of their operation life-spans. The assessment data of a resilience indicator usually is not measured or taken daily or in a short time interval because the changes to reliability usually happens only after some considerable time has passed. Depending on the characteristics of the components, the frequency of data measurement may vary from weekly, fortnightly, monthly, quarterly to even longer time interval.

Generation component

Each type of generator has its own characteristics and generation mechanism that the time it takes to fail and require repair is different than the other types of generators. There is uncertainty in the availability of a generation and it is important to have a statistic record of its availability information so that proper maintenance schedule can be made, for example, a major generator is recommended to be scheduled for maintenance during off-peak season in a year such as during spring or autumn instead of during summer or winter. A highly available component can help to increase reliability of the overall system. The indicator value is set to range from 0 to 1 but is usually less than value 1. The reliability is higher when the indicator value is close to 1. Reliability indicator of a generation component unit is as follows.

$$rl_{gt} = \frac{MTBF_{gt}}{MTBF_{gt} + MTTR_{gt}} \qquad \text{(Eq. 11)}$$

- rl_{gt}: Reliability of generation component g at time t.
- $MTBF_{gt}$: Mean time between failures of generation component g at time t.
- $MTTR_{gt}$: Mean time to repair of generation component g at time t.
- g, t: Please refer to (Eq. 1) and (Eq. 2).

The values of MTBF and MTTR are usually obtained from manufactures or based on statistic records of the relevant generation unit. *Table 16* shows the assumed values of MTBF and MTTR, and the reliability performance of each generation unit.

Table 16 Reliability performance of generation components used in analysis

Generation type	MTBF (year)	MTTR (year)	rl_{gt}
Pumped-storage hydroelectric	1.00	0.20	0.83
Oil	1.00	0.20	0.83
LNG+LPG	1.00	0.20	0.83
Coal	1.00	0.30	0.77
Nuclear	2.00	0.50	0.80
Hydroelectric	1.50	0.30	0.83
Storage-based generation	1.00	0.20	0.83
Solar photovoltaic generation	1.00	0.20	0.83

Consumption component

Each demand-side user (or each type of building) has his or her own lifestyle or working schedule and functions that the participation rate in a DR event of one user is usually different that the other user. Participation rate of a user can vary from time to time in a day, weekday to weekend, and season to season which are all related to the function and activity of the user (building). Participation rate is usually unpredictable especially when users are given manual override or flexibility to choose the amount of electric energy in a DR event and therefore it is usually a statistically-based information. Many methodology is available to assess participation rate. When DR is used only for emergency situations, participation rate can be assessed based on the number of participated DR events. On the other hand, when DR is used beyond emergency situation, for an instance, as an operating reserve for ancillary services, participation rate can be assessed based on peak status in a day, or the overall participation in a day. In this study, participation rate of each user is assessed at every hour. The indicator value is set to range from 0 to 1 but is usually less than value 1. The reliability is higher when the indicator value is close to 1.Reliability indicator of a consumption component unit is as follows.

$$rl_{ct} = participation\ rate\ in\ demand\ response\ event$$

$$= \frac{drp_{ct}}{dre_{ct}} \qquad \textit{(Eq. 12)}$$

$$= pr_{ct}$$

- rl_{ct}: Reliability of consumption component c at time t.
- pr_{ct}: Participation rate in demand response event of consumption component c at time t.

- drp_{ct}: Accumulative number of participated demand response events of consumption component c at time t.
- dre_{ct}: Accumulative number of demand response events requested to consumption component c at time t.
- c, t: Please refer to (Eq. 1).

The reliability performance or the participation rate of each consumption component (building type) in DR event is shown in *Table 32* (page *99*).

Network component

The power lines of network component of a power grid system are connected with many other types of components such as transformers, capacitors and switches besides consumption and generation components. In addition, the configuration of a power line closer to the supply side is different than those closer to the demand side. These factors cause different reliability values for each power line. Similar to generation component, availability is used as the reliability indicator of a network component unit as shown in the following. The indicator value is set to range from 0 to 1 but is usually less than value 1. The reliability is higher when the indicator value is close to 1.

$$rl_{nt} = \frac{MTBF_{nt}}{MTBF_{nt} + MTTR_{nt}} \qquad \textit{(Eq. 13)}$$

- rl_{nt}: Reliability of network component n at time t.
- $MTBF_{nt}$: Mean time between failures of generation component n at time t.
- $MTTR_{nt}$: Mean time to repair of generation component n at time t.
- n, t: Please refer to (Eq. 1) and (Eq. 7).

Similar to generation components, the values of MTBF and MTTR of network components are usually obtained from manufactures or based on statistic records of the relevant network unit. *Table 17* shows the assumed values of MTBF and MTTR, and the reliability performance of each network component unit.

Table 17 Reliability performance of network components used in analysis

Network type	MTBF (year)	MTTR (year)	rl_{nt}
Feeder	1.00	0.20	0.83
Primary distribution line	1.00	0.10	0.91
Secondary distribution line	1.00	0.05	0.95
Bypass power line	1.50	0.20	0.88

4.5.5 Vulnerability indicator

Vulnerability is defined as an internal risk factor that is mathematically expressed as the feasibility that the exposed component may be affected by the phenomenon that characterizes the hazard to disturb power balance (Please refer to *4.4.4 Definition of vulnerability*). Similar to the other attribute indicators each power component has its own vulnerability indicator. If an adaptability indicator is the further extension of a redundancy indicator then a vulnerability indicator is a further extension of a reliability indicators because a vulnerability indicator also concerns about the failure timing of a system and goes beyond that to consider the consequences or severity of the failure to the performance and function of the subject.

Generation, consumption and network components

All the three components of the community system in this study are considered as critical infrastructures and components. Their vulnerability is assessed based on the probability of frequency of the component receiving damages from any disturbances and the criticality of impact the damaged component will cause to the system in the aspect of functionality (Montoya, 2010). The assessment methodology of vulnerability proposed by Montoya is adapted and the vulnerability indicator of each of the three component units is as follows.

$$\begin{aligned} vn_{gt,ct,nt} &= vulnerability\ index\ of\ component \\ &= vi_{gt,ct,nt} \end{aligned} \qquad \text{(Eq. 14)}$$

- $vn_{gt,ct,nt}$: Vulnerability of generation, consumption and network components g, c and n at time t, respectively.
- $vi_{gt,ct,nt}$: Vulnerability index of generation, consumption and network components g, c and n at time t, respectively.
- g, c, n, t: Please refer to (Eq. 1), (Eq. 2)and (Eq. 7).

First of all, the severity level of each power component needs to be decided: whether the breakdown of a component will result in catastrophic, critical, marginal or negligible consequence to the system which the component belongs to. Where in real practice, professional judgment is required, however in this study, the severity level of a component is assumed to be related to the dispatchability of the component. This assumption is based on the fact that the breakdown of a dispatchable component used to maintain power balance will cause more sever consequence to the power balance of a system. Therefore, the basic principle used in this study is that a component with higher dispatchability will have higher severity. *Table 18* shows the classification of severity of bulk power generation and distributed generation according to their respective dispatchability which was mentioned in *4.5.3 Adaptability indicator*. This study assumes that the bulk power remains as the major power supply a community system depends on and therefore the breakdown of any generation behind the bulk power generation cannot be neglected. By referring to the generation type (bulk power or distributed generation) and the dispatchability, severity of each generation type can be estimated as shown in *Table 19*.

Table 18 Classification of severity of generation component according to dispatchability

Dispatchability / Severity	Catastrophic	Critical	Marginal	Negligible
Bulk power generation	0.75~1.00	0.50~0.75	0.00~0.50	-
Distributed generation	0.75~1.00	0.50~0.75	0.25~0.50	0.00~0.25

Table 19 Severity of each generation type

Generation type	Dispatchability	Severity
Pumped-storage hydroelectric	1.0	Catastrophic
Oil	1.0	Catastrophic
LNG+LPG	1.0	Catastrophic
Coal	0.5	Critical
Nuclear	0.3	Marginal
Hydroelectric	1.0	Catastrophic
Storage-based generation	1.0	Catastrophic
Solar photovoltaic generation	0.0	Negligible

Similar classification of severity based on dispatchability is also applied to consumption components (*Table 20*). Consumption components or building types are classified into two classes: small and large-scale power consumer as shown in *Table 21*. This classification aims to show that a building type with low dispatchability but as a large-scale power consumer should have higher severity than another building type with low dispatchability and as a small-scale power consumer. By referring to the power consumer type (small or large) and the dispatchability, severity of each building type can be estimated as shown in *Table 22*. In case of network component, the severity of each network type or power line type is shown in *Table 23*. It is based on the fact that network at higher level such as feeders will affect more customers when it experiences any disturbances., whereas lower-level network such as secondary power lines will only affect small number of customers connected to it.

Table 20 Classification of severity of consumption component according to dispatchability

Dispatchability / Severity	Catastrophic	Critical	Marginal	Negligible
Small-scale power consumer	0.75~1.00	0.50~0.75	0.25~0.50	0.00~0.25
Large-scale power consumer	0.75~1.00	0.50~0.75	0.00~0.50	-

Table 21 Category of power user (FEBC, 2012, p. 4)

Large-scale power consumer	Small-scale power consumer
Commercial, hotel, office, hospital, school	House, small factory

Table 22 Severity of each building type

Building type	Dispatchability	Severity
Residential	1.0	Catastrophic
Office	0.8	Catastrophic
Commercial	0.8	Catastrophic
Hotel	0.8	Catastrophic
Factory	0.5	Marginal
School	1.0	Catastrophic
Hospital	0.2	Negligible

Table 23 Severity of each network type

Network type	Severity
Feeder	Catastrophic
Primary	Critical
Secondary	Marginal
Bypass (Total)	Critical

After estimating the severity, vulnerability index of a power component can be estimated by referring to *Table 24* and *Table 25*. The vulnerability index assessment matrix used in this study is adapted from Montoya's work which is also about studying resilience performance of a power transmission system. Vulnerability index is made and adapted to range from 0.01 to 1.00 (in order of increasing vulnerability) to match the value ranges of other indicators of this study. The way how vulnerability index of a component unit is decided is based on the reliability (ability to continue to perform its intended function) and the severity of the component. For example, the vulnerability index of a power component which frequently malfunctions or stops functioning (low reliability) will be rated as 1.00 if its unreliability will cause catastrophic consequences to the system, and 0.37 if the consequences is negligible. As the vulnerability of a component gets higher, it means that the component should be reviewed by relevant stakeholders from both supply and demand sides to reduce the vulnerability of the component either by repairing or replacing it. Again, similar to reliability, vulnerability assessment is usually made following a considerably long time interval, such as monthly and quarterly. In this study, the vulnerability of a component unit can increase when the component unit is damaged or deteriorated, and decrease when the component unit is strengthened or replaced with a better component.

Table 24 Vulnerability index assessment matrix (Montoya, 2010, p. 107)

Reliability / Severity	Catastrophic	Critical	Marginal	Negligible
0 ~ 0.2	1.00	0.90	0.69	0.37
0.2 ~ 0.4	0.95	0.79	0.58	0.22
0.4 ~ 0.6	0.84	0.74	0.48	0.11
0.6 ~ 0.8	0.64	0.53	0.32	0.06
0.8 ~ 1.0	0.43	0.27	0.17	0.01

Table 25 Vulnerability index and its corresponding vulnerability level and description (Montoya, 2010, p. 107)

Vulnerability index	Vulnerability level	Vulnerability description
0.01 ~ 0.17	Low	Acceptable without review
0.17 ~ 0.58	Medium	Acceptable with review by system manager
0.58 ~ 0.79	Serious	Undesirable (Decision maker acceptance needed)
0.79 ~ 1.00	High	Unacceptable

By using *Table 24*, general vulnerability performance of generation components used in the analysis (*Table 26*) can be determined with referring to *Table 16* for reliability performance and *Table 19* for severity of generation components, and general vulnerability performance of network components used in the analysis (*Table 27*) can be determined with referring to *Table 17* and *Table 23* for reliability performance and severity of network components. Analysis and assessment are made in hourly resolution that reliability (MTBF and MTTR values) of generation and network components usually do not change so much within such short time period and therefore the vulnerability performance of those components should not have much changes. However, reliability (participation rate in DR event) of consumption components varies from time to time that vulnerability assessment can be made for each hour and average value is used to represent the vulnerability performance of a consumption component for that day.

Table 26 Vulnerability performance of generation components used in analysis

Generation type	Vulnerability
Pumped-storage hydroelectric	0.43
Oil	0.43
LNG+LPG	0.43
Coal	0.53
Nuclear	0.32
Hydroelectric	0.43
Storage-based generation	0.43
Solar photovoltaic generation	0.01

Table 27 Vulnerability performance of network components used in analysis

Network type	Vulnerability
Feeder	0.43
Primary distribution line	0.27
Secondary distribution line	0.17
Bypass power line	0.27

4.5.6 Interdependency among indicators

The previous sections have introduced the definitions of the proposed assessment indicators in this study. The proposed indicators are not absolute that they are only the author’s perception of the appropriate representation of energy resilience. Other indicators besides those used in this study can be included or used to replace what the author has proposed so long as the proposal makes sense in the new context. In this study, several indicators have been proposed, the interdependency among those indicators and their characteristics are illustrated in *Figure 40*.

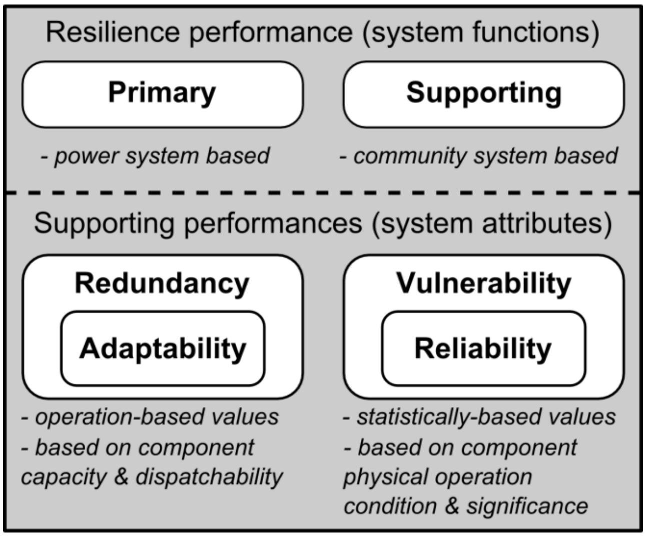


Figure 40 Interdependency among assessment indicators and their characteristics

As explained before that the functionality is the indicators of resilience performance and other system attributes are the supporting indicators of resilience indicators which are important to be taken into consideration. In the case of functionality indicators, primary indicator is based on performance of power system (power balance) because power energy is needed to perform activities that define the community functions. Supporting functionality indicators are significant community activities which define the performance of the community system. It has also been mentioned that an adaptability indicator is the further extension of a redundancy indicator and a vulnerability indicator is a further extension of a reliability indicators. Adaptability of a power component is assessed by measuring how much of the redundant capacity is dispatchable. On the other hand, vulnerability of a power component is assessed based on the reliability of the component and the severity consequences that could happen due to the unreliability of the component.

4.5.7 Key stakeholders' influences over indicators

It is necessary to show and understand how the proposed assessment indicators are being relevant to the key stakeholders so that each key stakeholder can understand their roles and influence on how to improve energy resilience of a community based on the assessment result. *Table 28* summarizes the influence each key stakeholder has to improve the performance of indicators proposed in this study.

Table 28 Key stakeholders' influences over assessment indicators

*(S: Supply-side decision makers & operators, D: Demand-side users, P: Policymakers or planners)

Indicator	Description of indicator	Key stakeholders' influences over indicator
FT1: power balance of daily power operation	A stable condition when power supply meets the requirement of power demand of a community system	**S**: Highly influential that their influences on other following indicators can be applied to influence the power balance. **D**: Highly influential that their influences on other following indicators can be applied to influence the power balance. **P**: Highly influential that their influences on other following indicators can be applied to influence the power balance.
FT2: demand users' convenience	A community objective that protect the demand-side users. It depends on the amount of demand response (DR) capacity committed by the users.	**S**: Users' convenience should be given higher priority over efficiency and economic concerns of operation during common situation. Users' convenience should only be reduced when there is an emergency. They can offer different DR programs to demand users and adjust the incentive rate given for every DR capacity committed by the users. **D**: Their cooperation and participation when a request of DR is made are very significant in determining if power balance can be achieved and partial or total blackout event can be avoided or not. If participation rate is low

Indicator	Description of indicator	Key stakeholders' influences over indicator
		and blackout occurs, some or all demand users are still eventually affected. **P**: Little influence.
FT3: cost of electric energy	A community objective that is a mutual interest of both supply and demand sides. It depends on the choices and capacity of generation units and required DR capacity to run a power operation.	**S**: Production cost is usually a top consideration but they also have to provide satisfactory service to demand users and fulfill other requirements (such as environmental requirements) from governmental organizations. They are responsible to decide the composition of power sources from sources with different production cost. **D**: Distributed generation and DR capacity are influential to reduce fluctuation of demand so that use of expensive supply-side operating reserve can be reduced. Demand-side users can decide whether to invest in distributed generation and participate in a DR event or not. **P**: They usually protect demand users by monitoring the cost of electric energy so that it is kept within acceptable range. They also amend policies to meet current needs and feasibility.
Redundancy: Stable generation	It depends on the remaining generation capacity of a stable generation unit. Redundant generation capacity with high certainty can be used to response to changes of power demand so that users' activities can proceed without interruptions.	**S**: They are responsible to decide the types of generation units to use, prepare plans on how to deploy those generation units, schedule for maintenance and repair of those generation units in order to ensure optimum redundant capacity at all time. **D**: Little influence. **P**: Little influence.
Redundancy: Storage-based generation	It depends on the remaining storage capacity of an energy storage. In case of breakdown of bulk power supply, a battery storage can be a good backup or emergency power source to support users' activities.	**S**: A pumped-storage hydroelectric generation unit is highly responsive in power generation and consume cheap energy in night time to restate its original water level. They need to decide the storage and output capacity, and operation plan of the invested generation. **D**: Battery storage installed in communities can contribute to the optimization of power operation and function as a backup power source in case of interruption of bulk power supply. They need to decide the storage and output capacity, and operation plan of the invested generation. **P**: Little influence.
Redundancy: Intermittent generation	Redundant power capacity from an intermittent generation unit depends on its actual generation output. However, it is less significant than the other types of generation because of its intermittent generation output is dependent on weather conditions.	**S**: They can install large-scale mega solar farm and wind turbines to increase the proportion of renewable power generation. They are the primary decision makers to decide the installed capacity of supply-side intermittent generation. **D**: They can install micro wind turbines, solar photovoltaic or thermal panels onto buildings. They are the primary decision makers to decide the installed capacity of demand-side intermittent generation. **P**: They can amend or create policies related to intermittent generation such as adjusting feed-in tariff to influence the investment of intermittent generation from supply and demand sides.
Redundancy: Consumption	It depends on the remaining DR capacity of a user (building type). Redundant DR capacity can be used to achieve power balance to prevent the occurrence of blackout which can cause critical consequences to community members.	**S**: Users' convenience should be given higher priority over efficiency and economic concerns of operation and therefore DR request should only be made when the supply side needs it for stabilizing a power operation. They can offer different packages of DR programs to demand users and decide the incentive rate for every DR capacity committed by the users. **D**: Their cooperation and participation when a request of DR is made are very significant in determining if power balance can be achieved and partial or total blackout event can be avoided or not. If participation rate is low

Indicator	Description of indicator	Key stakeholders' influences over indicator
		and blackout occurs, some or all demand users are still eventually affected. **P**: Little influence.
Redundancy: Network	It depends on the remaining power flow capacity of a power line. It determines how many more power capacity it can carry before it has to turn off itself in order to avoid damages due to overloading.	**S**: They decide the network layout, choice of power components such as capacitors and transformers to be used together with the network. Those decisions affect the performance and requirement of maintenance and repair of the network. The decided types of cables to be used as feeders, primary and secondary power lines will affect the allowable power flow capacity of those power lines. **D**: Little influence. **P**: Little influence.
Adaptability: Stable generation	An adaptable generation unit is highly dispatchable that it can ramp up or down its generation output within a short time to follow instantaneous changes of power demand. Redundant generation which requires long hour to ramp up or down its output is less helpful in dealing with instantaneous change.	**S**: They are responsible to find out the appropriate amount of dispatchable generation capacity to be included into the composition of power sources. They also need to decide the operation plan to use it together with other generation units to ensure stable power operation. **D**: Little influence. **P**: Little influence.
Adaptability: Storage-based generation	A battery storage is a good solution especially as a microgrid concept but there are also battery storages which are less dispatchable and that will reduce the ability to response to sudden changes of a power operation.	**S**: They are responsible to decide the necessary amount of dispatchable storage-based generation units, their capacities, and how to use them together with other generation units. **D**: They are responsible to decide the necessary amount of dispatchable storage-based generation units, their capacities, and how to use them together with other generation units. **P**: Little influence.
Adaptability: Intermittent generation	Current technology of intermittent generation still carries a high degree of uncertainty which can be a potential risk to a community if taken as a part of dispatchable generation. Unless its uncertainty can be improved or else it is better off considered as unadaptable or non-dispatchable.	**S**: They are responsible to perform research and development of this technology in order to increase its certainty in daily use so that its dispatchable capacity can be considered as a contribution to energy resilience. **D**: Little influence. **P**: Little influence.
Adaptability: Consumption	Whether a user can quickly cut off power consumption depends on what the user is doing, the time and season and other factors. It is critical to see if the demand reduction can help to achieve power balance in time or not.	**S**: Very little implication and influence. **D**: Only ongoing power demand are potential DR capacity. It is highly difficult but a way to improve adaptability of DR capacity is to try to perform significant activities during off-peak hours but less significant activities during peak hours so that when it is necessary like in an emergency, the power demand of those less significant activities can be used as DR capacity. **P**: Little influence.
Adaptability: Network	Availability of bypass power lines means that power supply can be delivered in many alternative paths if the existing one breaks down so that demand users will not be affected.	**S**: They are responsible to decide the amount and location of bypass power lines for best energy performance. **D**: Little influence. **P**: Little influence.

Indicator	Description of indicator	Key stakeholders’ influences over indicator
Reliability: Generation	It depends on the availability of a generation unit during its service period before it fails. A highly reliable generation unit increases the chance of a power operation to run properly without problems.	**S**: They are responsible to use reliable parts for a generation unit, schedule timely inspection for it and repair or replace it if it is broken, so that the generation unit performs properly and does not fail unexpectedly half way during a power operation. **D**: They are responsible to inspect distributed generation unit installed in their community, repair or replace it if any is broken, so that the distributed generation unit performs properly does not fail unexpectedly half way during a power operation. **P**: Little influence.
Reliability: Consumption	It depends on a user’s participation rate in DR events. A high participation rate means that a user is frequently fulfilling the DR request. This highly reliable source of DR capacity can be dispatched when necessary.	**S**: They can offer different DR programs to demand users and adjust the incentive rate given for every DR capacity committed by the users. **D**: A user should be taught or self-aware that if participation rate is low and blackout occurs, some or all demand users are eventually affected. **P**: Little influence.
Reliability: Network	It depends on the availability of a power line during its service period before it fails. A highly reliable power line increases the chance of a power operation to run properly without problems.	**S**: They are responsible to use reliable parts for a power line, schedule timely inspection for it and repair or replace it if it is broken, so that the power line performs properly and does not fail unexpectedly half way during a power operation. **D**: Little influence. **P**: Little influence.
Vulnerability: Generation	It depends on the reliability of a generation unit and the severity of the consequences if the generation unit becomes unreliable. A highly vulnerable generation unit is like a timed bomb to a power operation and it needs to be improved.	**S**: They are responsible to assess from time to time the reliability and possible severity of all supply-side generation units and improve any generation unit that is highly vulnerable. **D**: They are responsible to assess from time to time the reliability and possible severity of all generation units installed in their own building sand improve any generation unit that is highly vulnerable. **P**: They are responsible to have a representative to assess from time to time the reliability and possible severity of all shared generation units installed in a community and improve any generation unit that is highly vulnerable
Vulnerability: Consumption	It depends on the reliability of a source of DR capacity and the severity of the consequences if the source becomes unreliable. A highly vulnerable consumption unit is like a timed bomb to a power operation and it needs to be improved.	**S**: They can design several packages of DR programs which provide different levels of minimum participation rate of demand users to increase the reliability of users’ participation rate and subsequently reduce the vulnerability. Incentive rate or penalty rate can be utilized for the same purpose. **D**: It is highly difficult but a way to improve reliability and reduce vulnerability of a source of DR capacity is to try to perform significant activities during off-peak hours but less significant activities during peak hours. More often than not, a DR request is initiated during peak hours, a user is very likely to fulfill the request when the user is only performing less significant activities at that time. **P**: Little influence.
Vulnerability: Network	It depends on the reliability of a power line and the severity of the consequences if the power line becomes unreliable. A highly vulnerable power line is like a timed bomb to a power operation and it needs to be improved.	**S**: They are responsible to assess from time to time the reliability and possible severity of all power lines and improve any power line that is highly vulnerable. **D**: Little influence. **P**: Little influence.

4.6 Analysis component

The objectives, scopes, scales, system boundaries, concepts and indicators are already defined and now in this analysis component which is a part of the proposed assessment model, an analysis model needs to be formulated. The analysis model will include the modeling of a community system and its power components, and the simulation of daily power operation of the community system under various disturbances condition. *Figure 41* illustrates how the community system and its power components are modeled in a bottom-up approach. Comprehensive explanation of each modeling process is given from *4.6.2 Modeling community system* to *4.6.5 Modeling power network component*. This analysis model is used to simulate scenarios with different DR capacity in case study and the analysis results are used in the assessment model to study the effect of DR capacity on energy resilience of communities. *Figure 42* shows the variables and parameters used in the analysis model. Independent parameters and variables are marked differently.

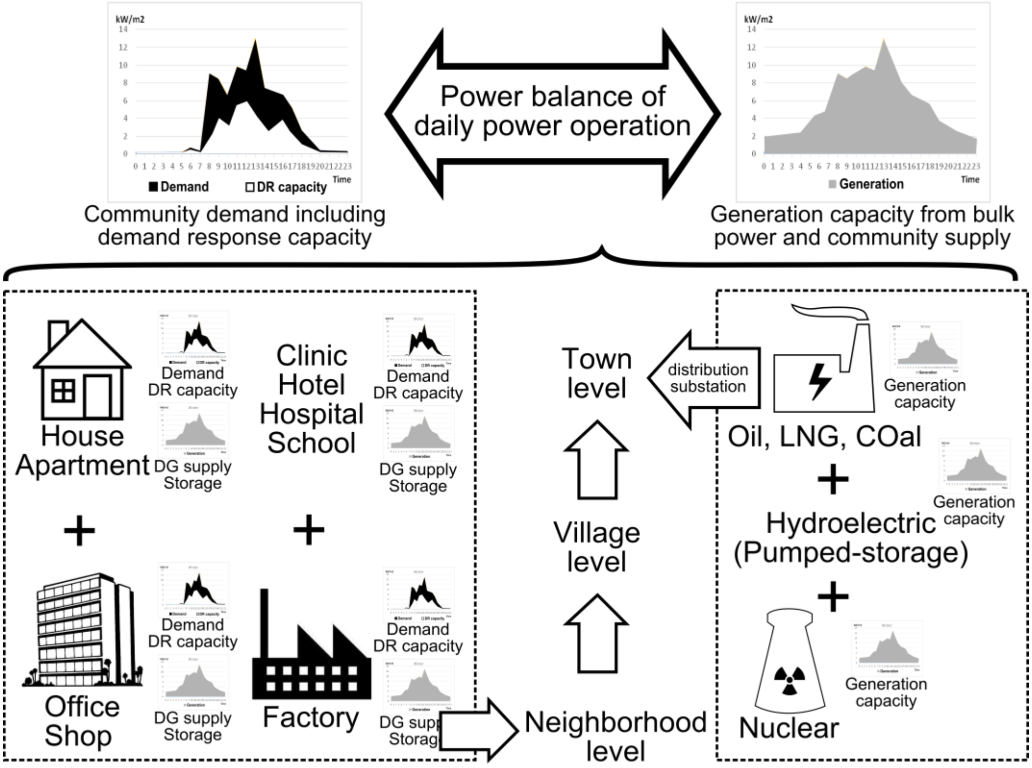
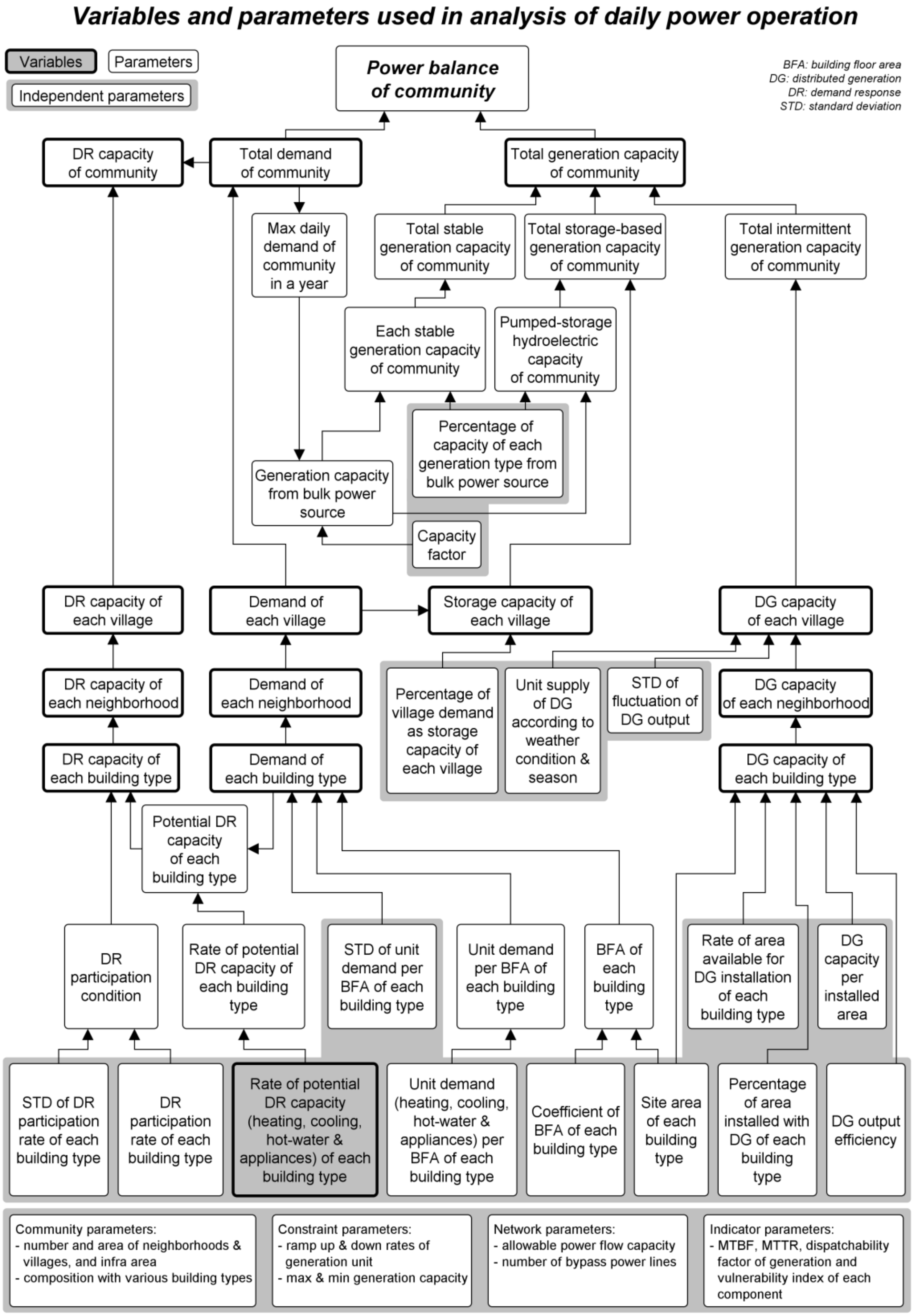


Figure 41 Modeling a community system and its power components from building level to town level to simulate daily power operation of the community

In different case studies of different town-level community, the characteristics of the specific community system and its power components will be reflected by changing the values of parameters related to a community.



*Disturbances are simulated by changing the values of parameters

Figure 42 Variables and parameters used in analysis of daily power operation

4.6.1 Formulation of analysis model

The formulation of the analysis model including the objective, decision variables, objective functions and constraints is explained in this section.

4.6.1.1 Objective of analysis model

The objective of this analysis model is to model a community system and simulate its daily power operation so that the analysis result can be used to demonstrate the assessment methodology of energy resilience proposed in this study. Therefore, the analysis model is not meant to be used for practical purposes. A power operation in a community is a complicated process which involves many levels of interactions among the components within the community system. However, the analysis model in this study is limited to simulate the effects of DR capacity on the power balance of a community when disturbances happen. Disturbances to daily power operation can be modeled and simulated by changing the values of parameters.

4.6.1.2 Decision variables

Decision variables are parameters which can be controlled in real life so that stakeholders can make decisions to change or improve a system in order to achieve desired outcomes. DR capacity is the decision variable used in the analysis model to study the effect of DR capacity on the daily power operation of a community. This decision variable belong to the demand-side users as they have the complete rights to decide how much of their demand to be used for DR capacity and whether to participate and fulfill the request during a DR event. However, supply-side operators including power utility companies can have substantial influence this decision variable by adjusting the incentive given through the DR packages they can offer to the users. For example, they can increase the incentive to attract and encourage the users to response more frequently and with more capacity. Other possible decision variables to study energy resilience of communities have also been identified and the key stakeholders' influences over them are shown in *Table 29*.

Other decision variables are used also in this study for further discussion of the possibility on improving energy resilience, for example, to find out how optimization of other parameters can improve energy resilience of communities.

Table 29 Identification of possible decision variables of energy resilience and key stakeholders' influences over them

Decision variables	Demand-side users	Supply-side operators	Policymakers & planners
Demand response capacity	○	△	×
Participation rate in demand response	○	△	×
Distributed generation capacity	○	×	△
Demands-side battery storage capacity	○	×	△
Composition of bulk power source	×	○	△
Capacity factor	×	○	△

4.6.1.3 Objective function and constraints

Assessment data requires result from a daily power operation of a community. The power operation can be optimized to achieve desired objectives or purposes such as cost, environmental requirement and users' comfort. When more than one objective needs to be met, then the priority of those objectives should be decided among key stakeholders and multi-objective optimization can be made to optimize a power operation. In this study, only one objective function which is the cost of electric energy is used to optimize the daily power operation of communities. Cost of electric energy is a practical objective function which is a concern of both supply and demand sides. Matlab is used to run the optimization analysis. The objective function which is also a functionality indicator of energy resilience can be written mathematically as below:

Objective function

$$\text{Minimize } FT3 \tag{Eq. 15}$$

- $FT3$: Please refer to (*Eq. 2*).

The analysis and optimization of daily power operation are subject to the general constraints of a power operation. Those constraints are:

- Power balance: the total supply must match the total demand at all time.
- Condition of DR: DR is only initiated when generation capacity is not enough to match the power demand at a time.
- Characteristics of battery storage: charging (demand) happens in night time and discharging (supply) happens in day time.
- Minimum and maximum generation output: each type of generation has different operation characteristics. Most of them have the requirements of minimum and

maximum generation output at any time to ensure efficient operation condition and avoid straining and shortening the lifespan of the generation unit.

- Ramp rates: ramp-up and ramp-down rates of a generation unit determines how much change of capacity can be increased or decreased in a unit of time. For example, a nuclear power plant has very low ramp rates but a hydroelectric power plant has high ramp rates.

Besides the constraints of power operation, the lower bound and upper bound of decision variables; DR capacity and participation rate of each building type (consumption components) are also defined. The DR capacity and participation rate will vary according to the significance of building function, peak status and season.

4.6.2 Modeling community system

A town-level community system and its power components need to be modeled to simulate its daily power operation. A community consists of villages and neighborhoods, and the power components consist of generation, network and consumption components. It is important to note that when generation and network components are each representing power components that provide power supply and deliver power, the consumption component here is used to represent not only the power demand, but also the DR capacity. The process of modeling community system is illustrated in *Figure 43*.

First of all, a town of interest is selected as the community system. A town usually consists of three to eight villages and a village can have about ten to one hundred or so neighborhoods depending on the size of the village (*Figure 43a*). A town is further broken into neighborhood level to model power components located inside each neighborhood (*Figure 43b*). Area of each neighborhood is measured and percentage of each building type within a neighborhood is visually estimated through the use of Google Maps. In the early stage of estimating site area of each building type, 12 building types are considered. The site area will be multiplied with a coefficient of building floor area (BFA) to estimate the building floor area of a building type. The value of this coefficient takes into account the average number of floor of a building type in a town and therefore it varies from one town to another town (*Table 30*). Eventually the 12 building types will be integrated into 7 distinctive building types in the analysis: residential building, office, commercial building, hotel, factory, school and hospital (*Figure 44*).

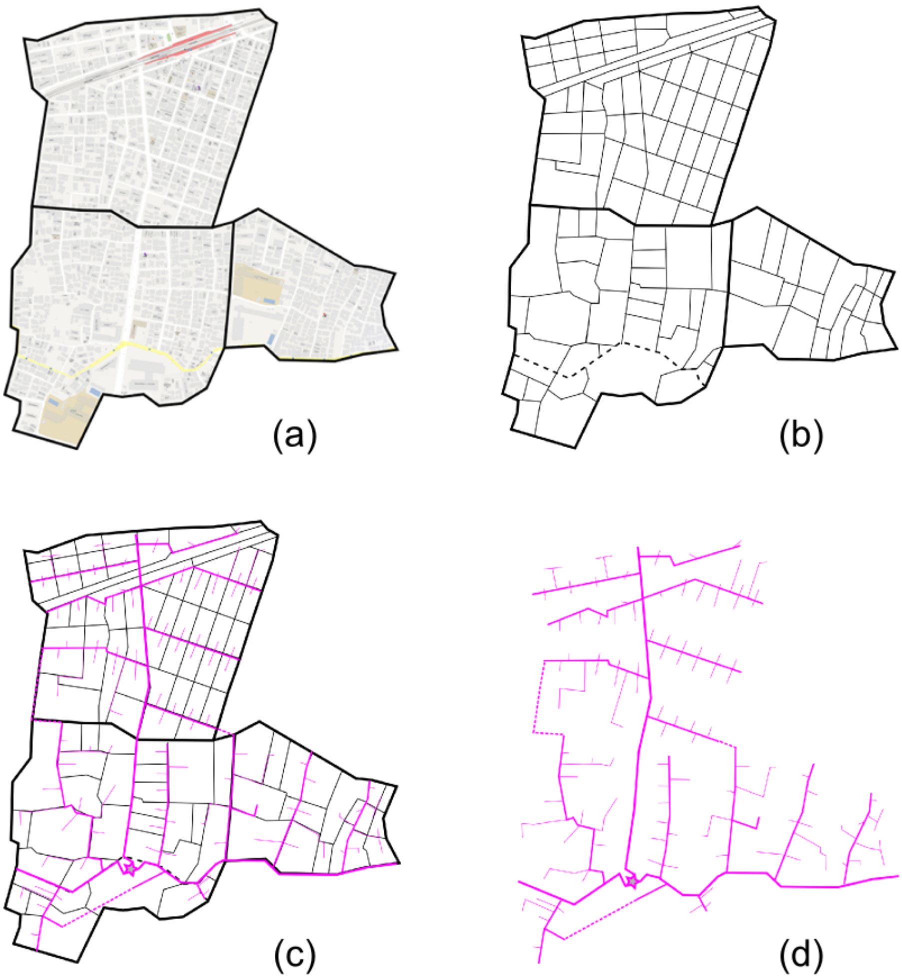


Figure 43 Modelling community system, (a) A community consisting of three villages, (b) Further breakdown of a community into neighborhood, (c) Power distribution network in community, and (d) Power network layout for analysis model

Table 30 Example of coefficient of BFA of building types in Ginza town

Building type	Coefficient of BFA
House	8
Apartment	10
Office (Standard)	8
Office (OA)	10
Shop	10
Clinic	8
Hotel	10
Sports	3
Factory	3
Others	2
School	2.5
Hospital	2.5

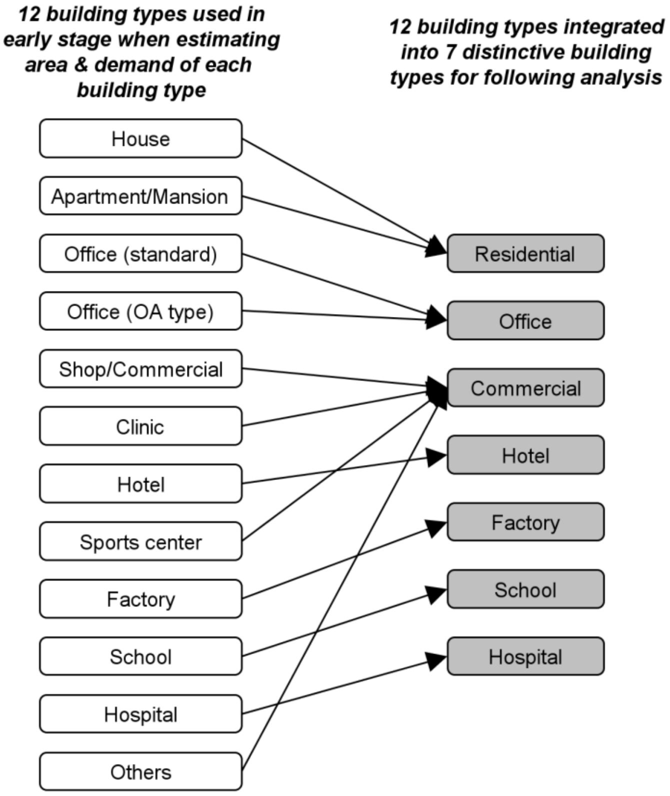


Figure 44 Integration of 12 building types into 7 distinctive building types

4.6.3 Modeling power consumption component

Regarding the power components inside a neighborhood, building types of different functions are modeled as consumption components that consume power and contain potential DR capacity (*Figure 45*). Power demand of a building type is modeled by first summing up all of its unit demands per building floor area (BFA) for energy uses such as heating, cooling, hot-water making and electric appliances and then multiplying it with the BFA of the building type. The unit demand per BFA of a building type varies according to seasonal effect. The unit demand per BFA for different energy use is based on the information from a Japanese cogeneration plan and design manual with minor adjustment to create unit demand per BFA for additional building types such as apartment, school and factory [日本エネルギー学会, 2008, pp. 62-69]. The data used in the analysis of this study can be referred to from *Appendix 10* to *Appendix 22*. When modeling power demand, a unit demand per BFA of a building type is considered as the mean for all the same building type in the community and then it is used with a standard deviation (*Table 31*) to generate randomized power demand for each building by following a normal distribution.

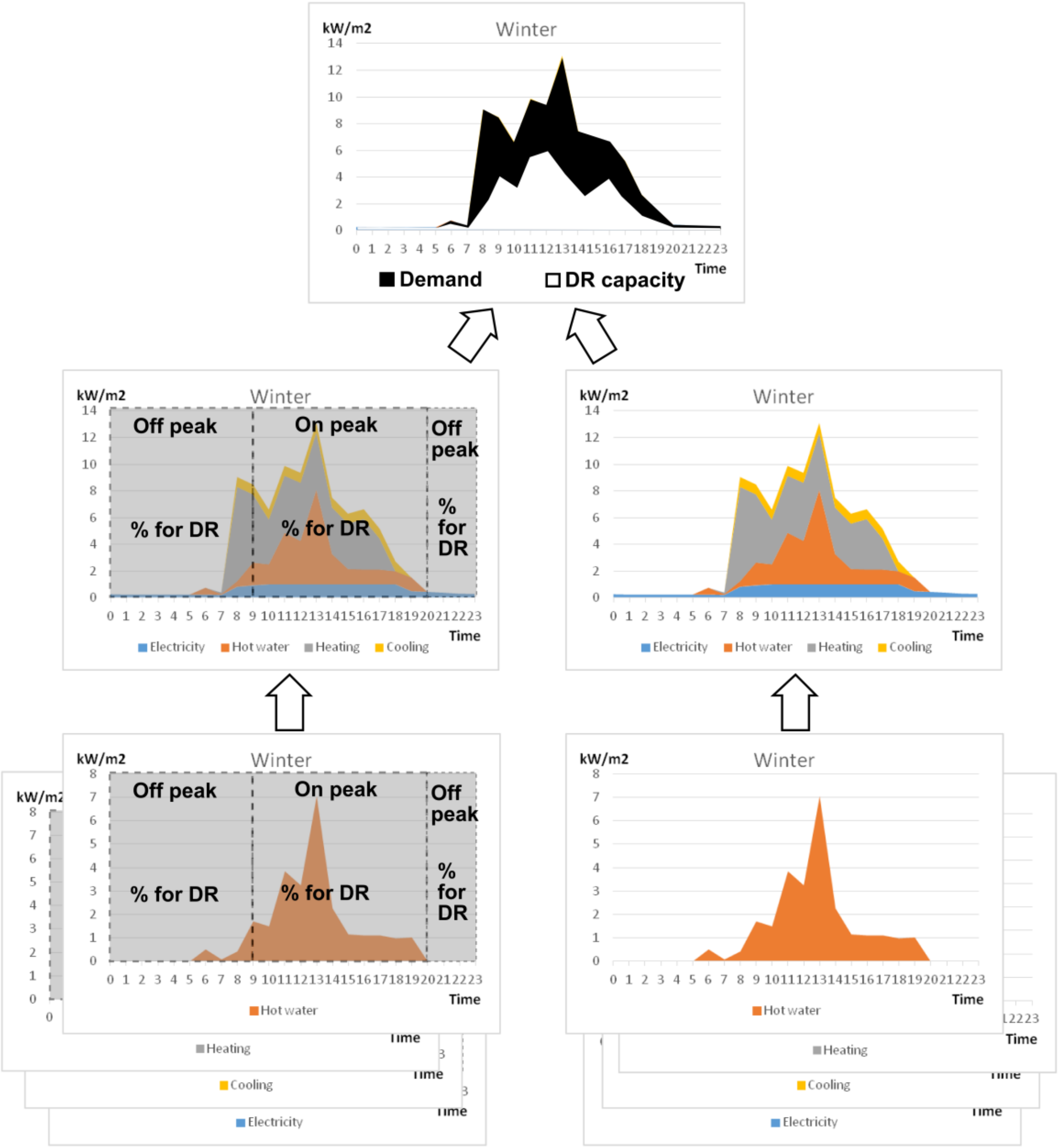


Figure 45 Bottom-up approach in modeling power demand of a building type based on inventory of energy use and estimating demand response capacity from the power demand based on consideration of peak status and building types

This study aims to better understand the effect of DR capacity on energy resilience of communities. For that purpose, maximum DR capacity is required to be modeled and used as a decision variables in the simulation of case study. In this study, all of the buildings are envisioned to be equipped with complete building energy management system (BEMS) like smart meters, electric appliances controllable by remote DR aggregators or power utilities companies and other required equipment necessary to perform smooth operation of DR. In addition, this study adopts the DR implementation approach that only requests the users to reduce their power demand when the stability of power operation is at risk. Under this DR approach, existing pricing plan remains unchanged and the demand reduction due to pricing plan effect is non-existing.

Therefore, DR capacity is defined in this study as the power demand that users will *potentially* reduce when requested by the power utility company when the stability of power operation is at risk.

As there is no available and reliable statistical information regarding the DR capacity of each building type, the best effort from the author is to estimate DR capacity as the percentage of ongoing power demand which can be turned off by considering the factors of seasons, peak status and significance of building function. This estimation approach of DR capacity is very similar to modeling power demand that it is estimated by beginning from the unit demands per BFA for energy uses such as heating, cooling, hot-water making and electric appliances (*Figure 45*). Estimation of DR capacity is made for 12 building types and the result is included in *Appendix 9*. The estimation results represent the maximum DR capacity of each building type.

Table 31 Standard deviation of unit demand per BFA for each building type used to generate randomized power demand of each building by following a normal distribution

Building type	Standard deviation of unit demand per BFA as the percentage of mean value		
	Off peak 0000-0900	Off peak 0900-2000	Off peak 2000-2400
House	10	20	30
Apartment	10	30	30
Office (Standard)	5	30	5
Office (OA Type)	5	30	5
Shop	5	30	5
Clinic	5	20	5
Hotel	20	30	30
Sports	5	20	5
Factory	20	40	20
Others	5	30	5
School	10	30	5

Users' needs during different seasons are different, for example, cooling is more needed during summer than spring, and heating is more needed during winter than spring. As a result, the percentage of power demand for cooling during summer to be used as DR capacity is less than the value during spring and the percentage of power demand for heating during winter to be used as DR capacity is less than the value during spring. When considering of peak status, users' activities must also be considered as well. The challenge of power balance is bigger during peak hours and that timing is also when most important activities are being performed. Considering about productivity and activities during peak hours, the percentage of power demand an office user is willing to allocate as DR capacity is supposed to be less than that of a residential user. On the other hand, during off peak hours in night time, a residential user is supposed to want to rest and enjoy the night at home and therefore the residential user will allocate lower percentage of power demand as DR capacity. However, an office user can assign almost all of the power demand in night time as DR capacity because the office activities is minimal then and the consequences of losing the power supply is less significant as well. In case of the consideration of significance of building function, buildings with significant functions such as hospitals, data centers, fire station and so on which will incur substantial risk of loss of lives and properties, usually have very low DR capacity than other buildings with less significant functions.

By signing up a DR agreement, a user is subject to various terms and conditions of the agreement that due to the agreement binding, a user is expected to be more participative in DR events. DR is expected and necessary to be automated so that it can be a set-and-forget task to the users. However, in most cases or many difference DR program offers, a user should be given the rights and ability to manual override the automated program, be it for the purpose of facing critical situations or less important reasons. This kind of human factor is also important to be taken into consideration. While there are many sophisticated methods to model human behaviors such as using game theory, this study has adopted a simple probability-based method. This human factor is called as participation rate in DR event of a building user which also works as the reliability indicator of power consumption components. Again, this kind of useful information or relevant study is not available and estimation of the participation rate of each building type has to be made based on the consideration of significance of building function as in the case of estimating DR capacity. *Table 32* shows the estimated participation rate and also its estimated standard deviation that both parameters are used to generate randomized participation rate for each building by following a normal distribution.

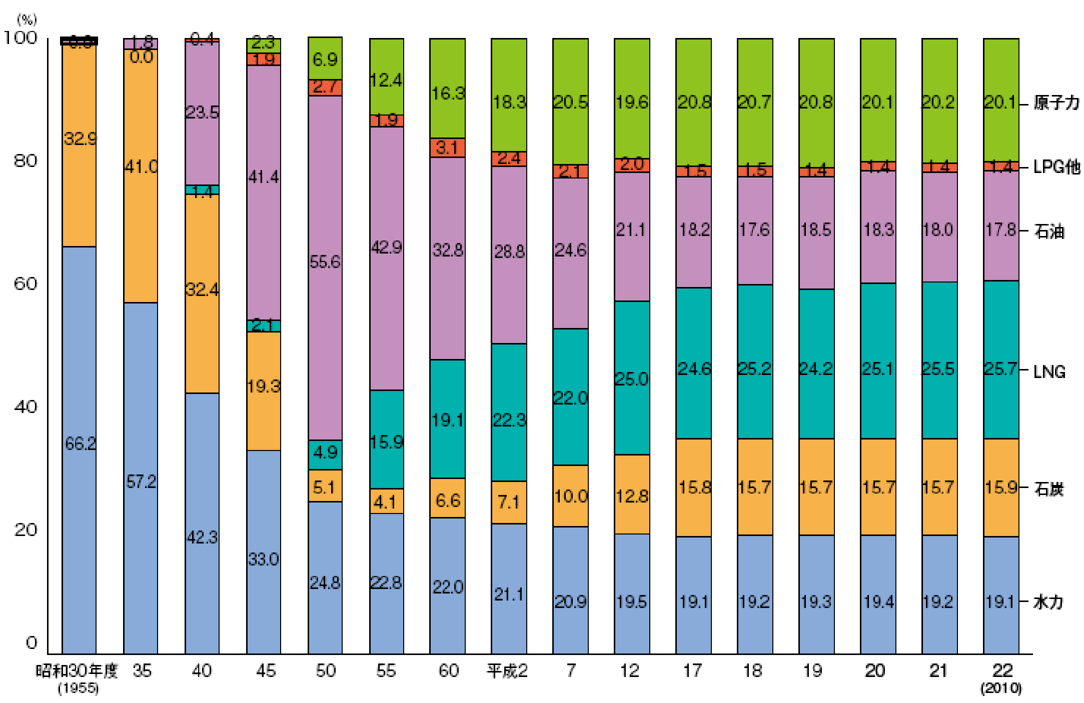
Table 32 Mean and standard deviation of participation rate in demand response event of each building type used in case study

	Mean participation rate in demand response event			Standard deviation of participation rate in demand response event		
Peak status/ Building type	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Residential	0.80	0.80	0.60	0.05	0.20	0.20
Office	0.80	0.70	0.80	0.10	0.10	0.10
Commercial	0.80	0.60	0.80	0.10	0.20	0.10
Hotel	0.50	0.50	0.50	0.15	0.15	0.15
Factory	0.70	0.50	0.70	0.10	0.20	0.10
School	0.80	0.80	0.80	0.05	0.05	0.05
Hospital	0.30	0.15	0.30	0.05	0.05	0.05

4.6.4 Modeling power generation component

There are three kinds of power generation components: stable, intermittent and storage-based generations. A stable generation component is represented by the bulk power supply of the community. A bulk power supply is delivered to a community through a power distribution substation (marked as a star in *Figure 43c*) and from there it is distributed to community members through the distribution network system. In reality, there is no way to judge the sources of the bulk power supply because the power supply generated from centralized power plants around a country is interconnected and distributed all around the country that it can be said to be impossible to track the power sources for a certain area. Different types of power plants have different characteristics and influences in a resilient power operation and therefore they are also included in the assessment as the power generation components. For the purpose of considering the effect of different power plant (which in this study, is secondarily important after the effect of DR capacity) on energy resilience of community, this stable generation component at town-level is considered as composed by oil, LNG, coal, nuclear and hydroelectric based generations. The bulk power supply is modeled to try to follow the national power source composition of Japan (*Figure 46*) but changes are needed for case study. The reference power source composition is based on the national power demand but the selected town communities in the case study in the later chapter are different in the aspect of community composition by various building types. This difference is significant in deciding the capacity of base-load power plant such as nuclear power plant. *Figure 47* shows the assumed composition of bulk power supply used in case study which is adapted from an official information of national power source composition of Japan. It is also essential to provide power reserve meet the changes in power demand. *Figure 48* shows the capacity factor and reserve factor of Japan power industry and capacity factor of 0.8 is used in the analysis of this study to decide the capacity of each power plant.

●電源別発電設備構成比（10電力計（受電を含む））



（注）1. 昭和45年度までは9電力計
2. LPG他：LPG、その他ガス、地熱、新エネ

（出典）電気事業連合会調べ

Figure 46 Japan power source composition (FEBC, 2012, p. 36)

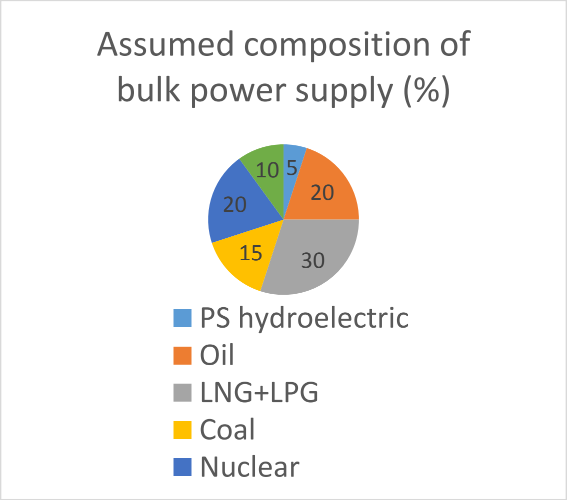


Figure 47 Assumed composition of bulk power supply used in case study

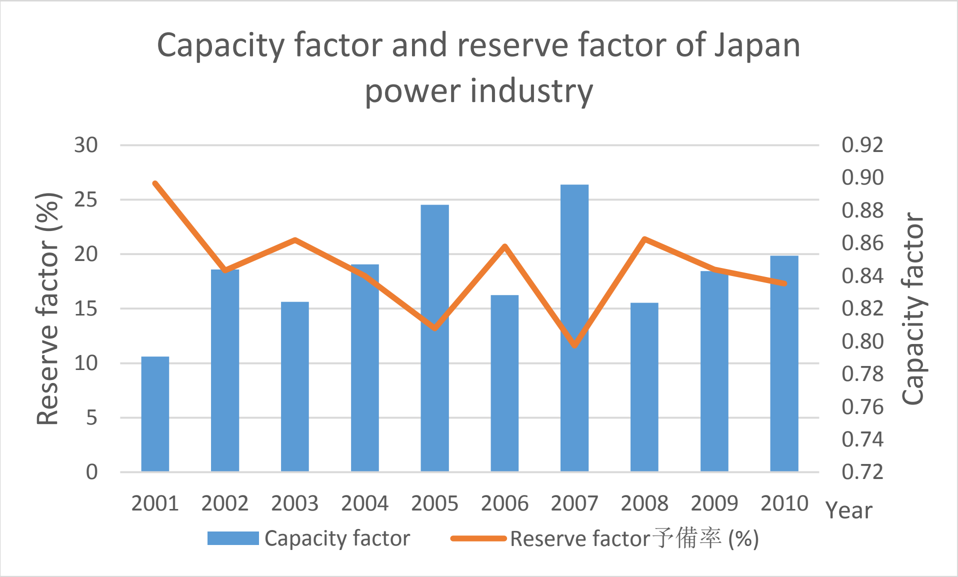


Figure 48 Capacity factor and reserve factor of Japan power industry (FEPC, 2013)

The second type of generation is intermittent generation which usually consists of distributed generation of renewable energy such as solar and wind generation within the community. Solar energy generation by photovoltaic panels is the kind of intermittent generation considered in this study and it is modeled from village level. The potential of solar generation is highly dependent on the available area for its installation. This study introduces two parameters to consider the installable area and *Table 33* shows the values of those parameters used in the case study. The first parameter is the percentage of total available area of a building type in a community used to install photovoltaic panels, and the second parameter is the coefficient of roof area available to install photovoltaic panels which aims to reflect that certain portion of roof area is not installable due to reasons such as pre-occupied with equipment, shape and angle of roof makes installation difficult or impossible. In addition,

Table 34 shows the values of other parameters related to solar generation used in this study. The rated capacity of photovoltaic panel is the average rated capacity of 77 photovoltaic panels by various manufacturers in Japanese market. The modeling of solar generation output is based on measured data and the average efficiency of the measured generation output is used as well. Feed-in tariff follows the actual rate announced in the year of 2013.

Table 33 Parameters affecting installable area of intermittent generation

Building type	Percentage of total available area of a building type in a community used to install photovoltaic panels	Coefficient of roof area available to install photovoltaic panels
Unused community area	10	0.9
Residential	10	0.8
Office	10	0.8
Commercial	10	0.8
Hotel	10	0.8
Factory	10	0.7
School	10	0.7
Hospital	10	0.7

Table 34 Rated capacity, efficiency and feed-in tariff of photovoltaic generation used in case study

Rated capacity of PV panel (kW/m2)	Efficiency of PV panel	Feed-in tariff (Yen/kWh)
0.14	0.85	37.80

The third type is the storage-based generation components which function as power supply sources in day time but power demand sources in night time. The storage-based generation within the community, such as a battery storage is modeled from village level, but the pumped-storage hydroelectric from the supply side is modeled at town level because it is part of the bulk power sources. *Table 35* shows the values of parameters related to storage-based generation used in this study. Besides that, generally the storage-based generation components in the analysis are modeled to charge themselves from time 2000 to time 0900 when discharging time is from 0900 to 2000.

Table 35 Parameters of storage-based generation used in case study

Parameter	Value
Maximum capacity of village battery storage (% of maximum daily power demand in a year of a village in kWh)	10
Starting battery capacity in a day (Storage capacity at 0000) (% of maximum battery storage capacity in kWh)	40
Maximum power capacity (% of maximum battery storage capacity in kW)	20
Cost of battery energy (Yen/kWh)	30

4.6.5 Modeling power network component

After modeling power generation and consumption components, distribution network system of the community is modeled with distribution feeders, primary and secondary power distribution lines. The network system is modeled as a radial network system. Each power line is modeled with an allowable power flow capacity to check if this power line is overloaded or not in a power operation. When in reality a power line is also subject to thermal limits and voltage drop limits, these limits are assumed to be under the proper control of other power equipment such as capacitors and regulators. The dotted lines in *Figure 43d* represent bypass power lines which is usually opened (switched off) and only used when existing power lines are damages or malfunction. Once the community model is complete and then simulation of daily power operation is made to obtain data for the assessment model.

4.6.6 Simplifications made in modeling

A power grid system is a complex system and a power operation of a town is also as complex as well because there are numerous factors affecting the operation itself. As this study is limited to demonstrate the proposed assessment methodology of energy resilience, the modeling of the community system and its power components have been simplified so that it is adequate enough to study of the effect of DR capacity on the energy resilience. Among the main simplifications made are listed below:

- The modeling of the distribution network system is simplified so that only power capacity is considered. The fluctuation of power voltage and frequency is assumed to be under the proper control of other power equipment such as capacitors and regulators.
- The modeling of the optimization of power operation is limited on the variables and parameters discussed in this study. Other factors such as free market bidding, users' behaviors, weather conditions, building conditions and so on are important when dealing with practical situation but they are isolated from this study. The isolation of less significant factors can also help to focus the whole analysis on the effect of DR capacity only.
- The forecasting of community demand can be based on complicated forecasting models. In this study, forecasting of community demand is modeled as another set of community demand with its unit demand per BFA at the bottom-level randomized following a normal distribution.

4.6.7 Simulation of daily power operation

Following the formulated objective, decision variable, objective function and constraints, simulation of daily power operation of a community model can be made in case study. The simulation covers the complete series of operations in a daily power operation from forecasting, scheduling, beginning and end of the actual operation (*Figure 7*, page *16*). Decision variables and parameters in this study are changed accordingly to simulate the situations and scenarios of interest. Reports and records of the changes are included in case study in the next chapter.

4.6.8 Power flow analysis

A power flow analysis is used to find out the magnitude and phase angle of the voltage at each power generation or consumption component, and the real and reactive power flowing in each power line. It is used in this study as a means to obtain power capacity flowing in the distribution power lines and also to verify the simulation results. If the allowable power flow capacity of a power line is exceeded, that means the simulation result is not feasible in reality and therefore simulation should be revised again. Otherwise, the result of power flow analysis (power flow of power lines), the result of simulation analysis (power generation, consumption and DR capacity), and other information of operation conditions (information of dispatchability factor, reliability, vulnerability of the power components) of the community system are used in the assessment model.

4.6.9 Verification and validation of analysis model

A significant step when modelling a system is to verify and validate the model to see if the model can really fulfill its intended purposes. *Figure 49* shows the relationships between reality and model, and that verification and validation of model are required to confirm if a model is representative of the reality or not.

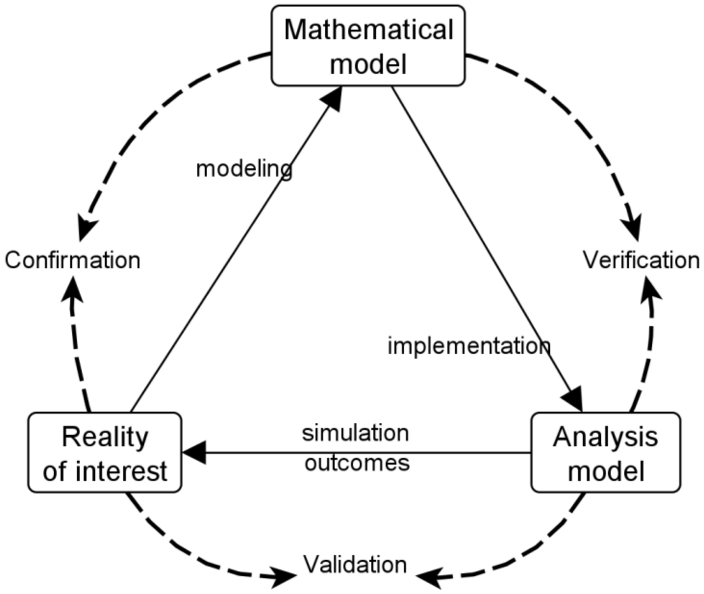


Figure 49 Verification, validation and confirmation of model to reality (adapted from (Schlesinger, 1979))

The aim and objective of this study is to propose assessment methodology of energy resilience of communities. Assessment model is developed and indicators are proposed in order to demonstrate how the proposed methodology can be applied in real life. The assessment model uses data from daily power operation. An analysis model has been made to model and simulate daily power operation of a community system so that the analysis results can be used by the developed assessment model. Verifying and validating the analysis model are to a limited extent equal to verifying and validating the assessment model itself.

In the analysis model, the best available data sources within the author's effort were used to increase the reliability of the model. Measured data such as generation output of solar photovoltaic generation, real town configuration and power consumptions of residential houses, and reliable references regarding typical power demand per building floor area of different building types, composition of bulk power sources and generation capacity of photovoltaic panel, have been used and adapted to establish the analysis model. Where and when an assumption has to be made, existing relevant data is based upon to make the assumption and it is clearly described so that readers can estimate the potential discrepancies of the outcomes due to the assumption made. The constraints of models such as power balance, upper bound and lower bound of decision variables are also used to check if an optimization is achieved without breaking the constraints. The power flow analysis is also used as a tool to verify the feasibility of simulation result.

Even though this study is limited on demonstrating the assessment methodology instead of developing a practical assessment tool, the author has consulted experts in power engineering industries and experienced professionals for their opinions of the proposed assessment indicators in this study. The proposed assessment indicators such as redundancy and adaptability indicators are defined based on their fundamental concepts, and reliability and vulnerability indicators used in this study are adoption of very well-established indicators and adaptation of reliable existing indicators. According to the opinions from the experts and professionals, the proposed assessment indicators in this study are acceptable but may not be the best or practical indicators used in the real life. As the objective of this study is to demonstrate the assessment methodology and also discuss the implication, usefulness and limitation of the proposed indicators, the author deems that the proposed assessment indicators are verified as fit to be used in the discussion of this study.

The validation of the assessment model is not feasible at the time of this study is made because the required information is not available or disclosed, for example, DR program in Japan has not included small-scale demand users such as residential users, the actual layout of power network of a town is not disclosed to the public and so on. In addition, as the resilience study is still new in the Japanese power industry and architectural study, the author tried but could not manage to find similar studies to be compared with this study. As a result, the author hopes that this study can be one of the few pioneer works in this cross-disciplinary topic which will be used as a reference and comparison material for more future similar studies. And by the time enough studies are made, validation of this kind of topic should be made.

4.7 Assessment and interpretation of energy resilience

After making the analysis that covers modeling a community system and simulating its daily power operation, the analysis results are used to make assessment. Assessment is made from bottom level. Three functionality indicators are considered for the overall system resilience performance and four attribute indicators are considered for the performance of each power component. In case of functionality indicators, the indicators are measured by using bottom-level analysis result. However, in case of attributes indicators, weightage has been assigned to take into account the difference of significance and capacity of each different component unit of a power component. For example, when a coal power plant with 10MW generation capacity and a village-level solar generation system with 1MW have identical redundancy value (in the case of each generation consuming only 10% of their generation capacity, redundancy for each generation is equal to 0.9), weightage must be used and assigned to take into account of the difference in maximum generation capacity. The same also applies to consumption and network components.

There are many possible ways of assigning weightage such as to base on maximum capacity, significance or performance characteristics and so on. In this study, weightage of generation component is assigned according to maximum generation capacity, weightage of consumption component is assigned based on percentage of a building type in a community composition, and weightage of network component is assigned according to the significance of a power line that feeder is assigned with 0.6 and primary power line is 0.4. Simple method is used to assign weightage in this study but there are also other alternative methods such as pairwise comparison. The weightage assignment method for each power component used in this study is shown in *Table 36*.

Table 36 Weightage assignment method for each power component

Power component	Generation	Network	Consumption
Weightage assignment method	Maximum generation capacity	Significance of power line type	Percentage of a building type in a community composition

The proposed indicators are assessed based on the analysis results and then the assessment result needs to be reported to provide meaning to the whole process of assessment. *Table 37* and *Table 38* show how the final assessment results of indicators can be presented in an assessment report of a community system. As mentioned in *4.5 Indicator component*, the functionality indicators represent the performance indicators of energy resilience of a community whereas other significant attribute indicators represent the supporting performance indicators of energy resilience.

Table 37 Example of reporting of functionality indicators

Functionality indicators	FT1: Power balance	FT2: Demand users' convenience	FT3: Cost of electric energy
Community system	-[FAIL/OK]+	-[0~1]+	+[Yen/kWh]-

Table 38 Example of reporting of attribute indicators

Component	Redundancy indicators	Adaptability indicators	Reliability indicators	Vulnerability indicators
Generation	-[0~1]+	-[0~1]+	-[0~1]+	+[0~1]-
Network	-[0~1]+	-[0~1]+	-[0~1]+	+[0~1]-
Consumption	-[0~1]+	-[0~1]+	-[0~1]+	+[0~1]-

It is important to provide a guideline and documentation on how to interpret the assessment result. The unit and value range of an indicator are included in a bracket "[ ]" that when no unit is provided then the indicator is "unitless" or dimensionless and when no value range is provided then the indicator is boundless. The positive and negative signs at each side of a bracket shows how the indicator value is interpreted. The negative sign at the left bracket side of all indicators expect for FT3 and vulnerability indicators can be interpreted that a smaller indicator value represents poor performance of that indicator, and on the other hand, the positive sign at the right bracket side represents better performance. The interpretation is the opposite for the FT3 and vulnerability indicators in which a larger indicator value represents undesired or poor performance of the indicator. Further explanation of the meaning of the values of indicators are covered from *4.5.1 Functionality indicator* to *4.5.5 Vulnerability indicator*. Under the bottom-up approach, each indicator value at the community system level is a collective result from the corresponding indicator values from lower level such as the village, neighborhood and building levels.

The analysis result showing the power balance status is the first determinant factor to decide if a community system is resilient or not. If a community system fails to achieve power balance in any specific scenario then it is considered as not resilient or unresilient otherwise assessment will proceed to the performances of supporting functionality indicators and attribute indicators. The performance of each supporting functionality indicators is then compared with its own benchmark value to determine if a community is resilient or not. If any functionality indicators shall perform lower than its benchmark value, then the community system is considered as not resilient because it fails to maintain its assigned functions. When a community system is declared as resilient, it means that the community system has managed to achieve power balance (a community function related to power system performance) and maintain the performance of its significant community functions (significant community activities depending on uninterrupted power supply) above benchmark or minimum level. On the other hand, if any attribute indicators shall perform lower than its benchmark value, then it becomes a sign or warning to indicate a weakness of the community and the resilience of the community is at risk. Improvement should be made to improve the indicator performance otherwise the community may lose its energy resilience. Regarding on how and what to do to improve energy resilience of a community, *4.5.7 Key stakeholders' influences over indicators* can be referred to because it provides clear information of each key stakeholder's responsibility and influence on the performances of indicators.

Chapter 5
Analysis and discussion

Case-study analysis was performed by using the developed assessment model in this chapter. The analysis included modeling a community and its power generation, network and consumption components. By varying the demand response capacity, daily power operations of the community under various level of disturbances were simulated and the results were used in the developed assessment model. The effect of demand response capacity on energy resilience of communities were examined. Discussion about the usefulness and implications of the proposed assessment methodology is given in the end.

5.1 Introduction

As a means to demonstrate the applicability and usefulness of the proposed assessment methodology to support the users in the process of decision making, simulation-based case study was made by using the developed assessment model. Design of case studies including the selection criteria of real-world towns and the profile information of the selected towns and their respective power components are reported. Each town represents a case study and identical simulation condition was applied to each case study and configured in a way that the analysis results would be capable to show the effect of demand response (DR) capacity on energy resilience of those communities. In addition, optimization of a community and its power components was also made to demonstrate the capability of the developed assessment model to be used to optimize the energy resilience of the community. Following the analysis part is the discussion of the results of analysis and assessment. The usefulness and implications, and the limitations of the proposed methodology are also discussed.

5.2 Design of case study

The main objective of the case-study analysis was to study the effect of DR capacity on energy resilience of communities. Besides that, it is also useful to find out what kind of town-level community is more resilient that the others and therefore three towns with different composition of building types were selected. The selection criteria and profile information of each town are given in the following sections.

5.2.1 Selection criteria

When selecting towns as the case-study subjects, towns with different characteristics were selected. As mentioned earlier in *2.1.2.1 Community as a solution*, the composition by building type of a community affects the overall community demand because different building types have different power demand patterns. Community composition has been a concern in the study of microgrid which is an essential factor in the study of resilience as well. A community which can perform well as a microgrid is arguably a more resilient community. As a result, town characteristics especially the town composition is a selection criteria.

In the case study, Umegaoka (梅ヶ丘) town represents a town highly composed with residential buildings, Toyosu (豊洲) town as a town with high percentage of high-rise buildings and mainly composed with residential, office and commercial buildings, and Kitakoujiya (北糀谷) town as a town highly composed with residential buildings and has a substantial percentage of small factories in the town. This study is focused on studying community system in urban area and therefore these case-study towns were selected from Tokyo urban area. The selection criteria also followed the spatial scale specified in *4.1.3 Scale and system boundary of assessment* that these selected towns are composed by two to five villages.

5.2.2 Town 1: Umegaoka town in Setagaya district

Umegaoka town in Setagaya district (梅ヶ丘、世田谷区) was selected as one of the three towns for the case study (*Figure 50*). *Figure 51* and *Figure 52* show the street views of Umegaoka town. Umegaoka town is made up of three villages and 115 neighborhoods and composed by more than 85% of residential buildings (Figure 53). Additional information specific to Umegaoka town is shown in *Figure 54*, *Figure 55*, *Table 39*, *Table 40* and *Table 41*. Other common information shared among the three towns are mentioned from *4.6.2 Modeling community system* to *4.6.5 Modeling power network component*. All the information is specific for August and forecasted daily power demand and the corresponding scheduling of daily power supply are shown in *Figure 56*.

Figure 50 Community and power distribution network layout of Umegaoka town case study

Figure 51 Street view of Umegaoka town (1)

Figure 52 Street view of Umegaoka town (2)

Case name	Umegaoka
Number of villages	3
Number of neighborhoods	115
Town area (km2)	0.51
Buildable area (km2)	0.46
Built area (km2)	0.28

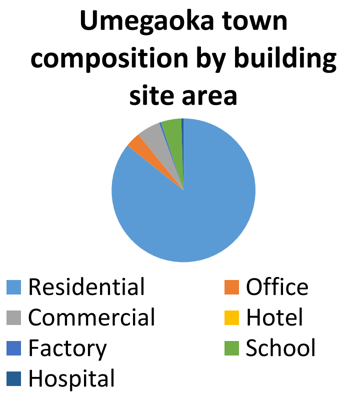


Figure 53 Profile of Umegaoka town and its composition by building type

Building type	Coefficient of BFA
House	2
Apartment	5
Office (Standard)	2
Office (OA)	2
Shop	2
Clinic	1
Hotel	3
Sports	3
Factory	1.5
Others	1
School	2.5
Hospital	2.5

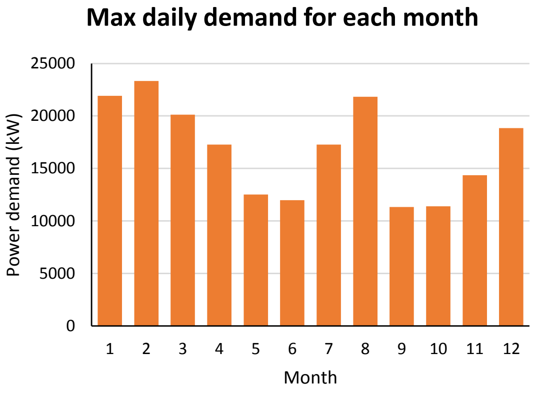


Figure 54 Coefficient of BFA of building types and estimated maximum daily demand for each month of Umegaoka town

Generation type	Capacity (kW)
Stable	22950.00
Intermittent	5185.47
Storage	7666.74
Total	35802.22

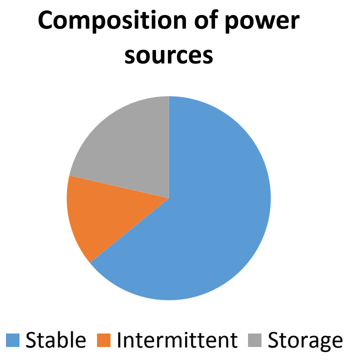


Figure 55 Composition of power sources in Umegaoka town by stable, intermittent and storage-based generations

Table 39 Profile of stable generation of Umegaoka town in August

Month	8					
Stable generation unit	Max power capacity (MW)	Max generation capacity (% of MW)	Min generation capacity (% of MW)	Ramp-up rate (% of MW/h)	Ramp-down rate (% of MW/h)	Cost (Yen/kWh)
Oil	5.40	100	5	80	-80	15.50
LNG+LPG	8.10	100	5	80	-80	6.50
Coal	4.05	100	10	50	-50	6.00
Nuclear	5.40	50	40	10	-10	5.50
Hydroelectric	2.70	100	10	100	-100	10.50

Table 40 Profile of intermittent (PV) generation of Umegaoka town

PV generation at village level	Total installed capacity (kW)
PV1	2150.09
PV2	2090.94
PV3	944.45

Table 41 Profile of storage-based generation of Umegaoka town in August

Month	8				
Storage-based generation unit	Max storage capacity (kWh)	Max generation capacity (kW)	Ramp-up rate (kW/h)	Ramp-down rate (kW/h)	Cost (Yen/kWh)
PS hydroelectric	14850	1350	1350	-1350	42.80
Storage1	15935	3187	3187	-3187	30.00
Storage2	11136	2227	2227	-2227	30.00
Storage3	4513	903	903	-903	30.00

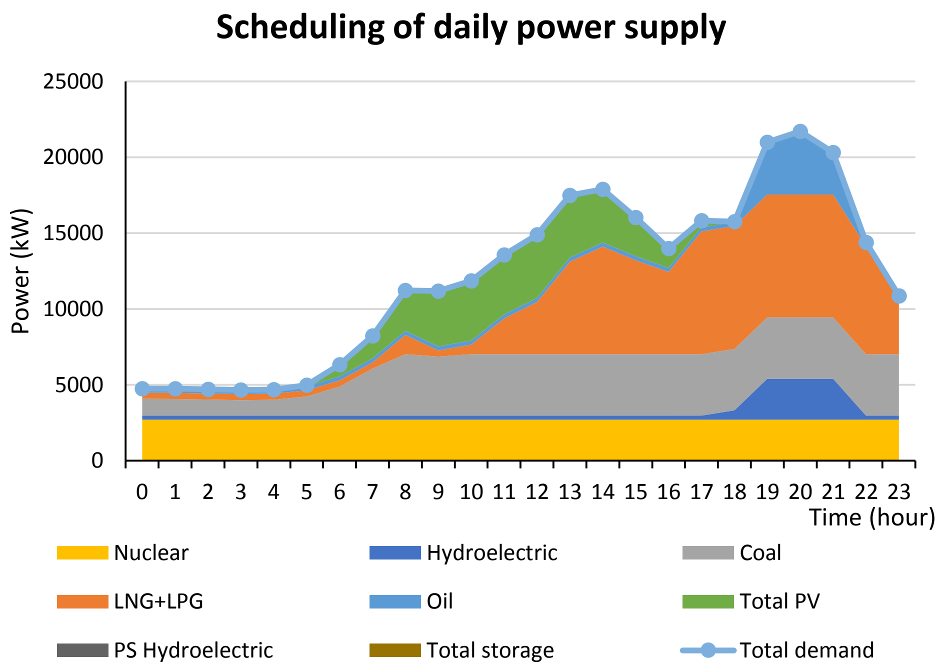


Figure 56 Scheduling of daily power supply to meet forecasted demand of Umegaoka town in August

5.2.3 Town 2: Toyosu town in Koutou district

Toyosu town in Koutou district (豊洲、江東区) was another town selected for case study (*Figure 57*). *Figure 58* and *Figure 59* show the street views of Toyosu town. Toyosu town is made up of five villages and 32 neighborhoods and composed by 38% of residential buildings, 28% of office and 23% of commercial buildings (*Figure 60*). Additional information specific to Toyosu town is shown in *Figure 61*, *Figure 62*, *Table 42*, *Table 43* and *Table 44*. Other common information shared among the three towns are mentioned from *4.6.2 Modeling community system* to *4.6.5 Modeling power network component*. All the information is specific for August and forecasted daily power demand and the corresponding scheduling of daily power supply are shown in *Figure 63*.

Figure 57 Community and power distribution network layout of Toyosu town case study

Figure 58 Street view of Toyosu town (1)

Figure 59 Street view of Toyosu town (2)

Case name	Toyosu
Number of villages	5
Number of neighborhoods	32
Town area (km2)	1.14
Buildable area (km2)	1.02
Built area (km2)	0.44

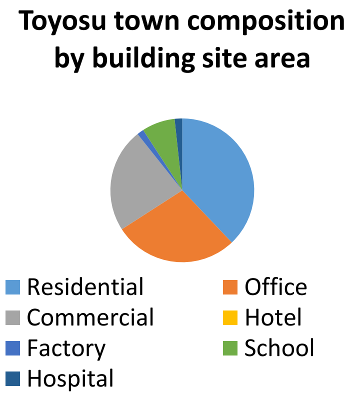


Figure 60 Profile of Toyosu town and its composition by building type

Building type	Coefficient of BFA
House	3
Apartment	20
Office (Standard)	10
Office (OA)	30
Shop	7
Clinic	2
Hotel	5
Sports	5
Factory	5
Others	3
School	7
Hospital	8

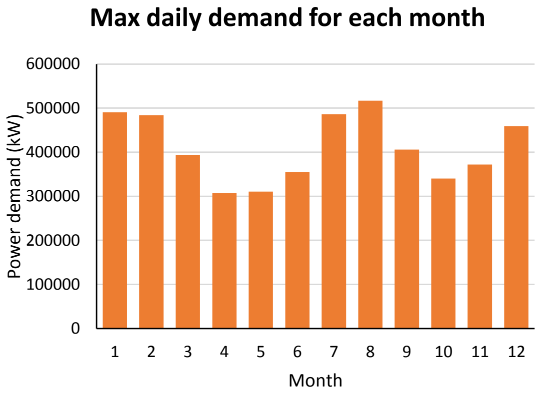


Figure 61 Coefficient of BFA of building types and estimated maximum daily demand for each month of Toyosu town

Generation type	Capacity (kW)
Stable	549100.00
Intermittent	11796.22
Storage	153870.39
Total	714766.61

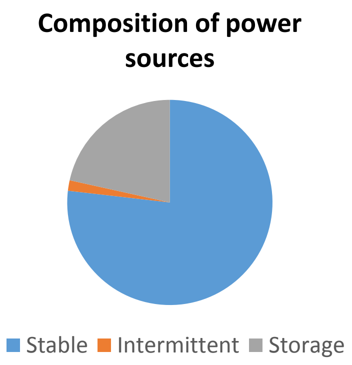


Figure 62 Composition of power sources in Toyosu town by stable, intermittent and storage-based generations

Table 42 Profile of stable generation of Toyosu town in August

Month	8					
Stable generation unit	Max power capacity (MW)	Max generation capacity (% of MW)	Min generation capacity (% of MW)	Ramp-up rate (% of MW/h)	Ramp-down rate (% of MW/h)	Cost (Yen/kWh)
Oil	129.20	100	5	80	-80	15.50
LNG+LPG	193.80	100	5	80	-80	6.50
Coal	96.90	100	10	50	-50	6.00
Nuclear	129.20	50	40	10	-10	5.50
Hydroelectric	64.60	100	10	100	-100	10.50

Table 43 Profile of intermittent (PV) generation of Toyosu town

PV generation at village level	Total installed capacity (kW)
PV1	1189.04
PV2	2538.70
PV3	3014.56
PV4	2477.13
PV5	2576.78

Table 44 Profile of storage-based generation of Toyosu town in August

Month	8				
Storage-based generation unit	Max storage capacity (kWh)	Max generation capacity (kW)	Ramp-up rate (kW/h)	Ramp-down rate (kW/h)	Cost (Yen/kWh)
PS hydroelectric	355300	32300	32300	-32300	42.80
Storage1	77367	15473	15473	-15473	30.00
Storage2	92402	18480	18480	-18480	30.00
Storage3	268539	53708	53708	-53708	30.00
Storage4	76358	15272	15272	-15272	30.00
Storage5	93186	18637	18637	-18637	30.00

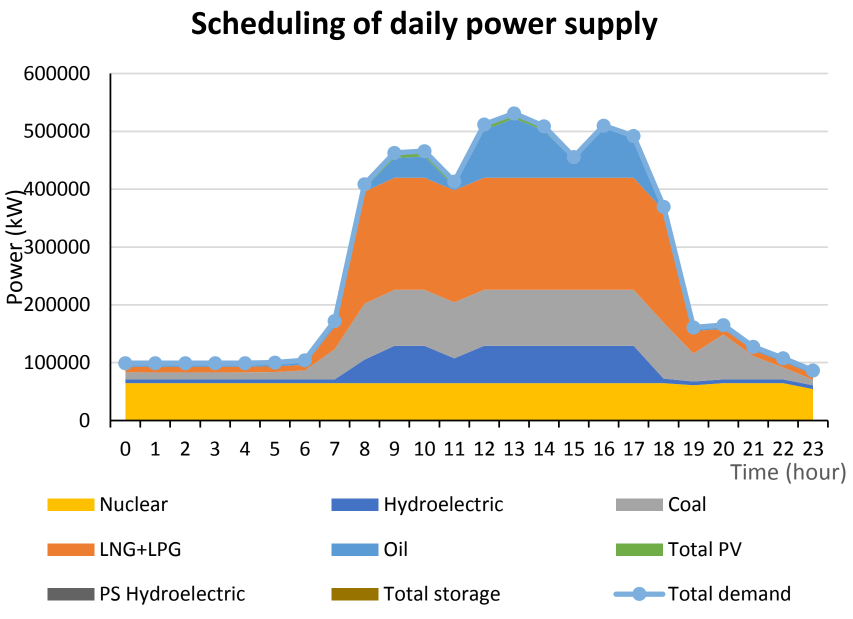


Figure 63 Scheduling of daily power supply to meet forecasted demand of Toyosu town in August

5.2.4 Town 3: Kitakoujiya town in Oota district

Kitakoujiya town in Oota district (北糀谷、大田区) was also a town selected for the case study (*Figure 64*). *Figure 65* and *Figure 66* show the street views of Kitkakoujiya town. Kitakoujiya town is made up of two villages and 39 neighborhoods and mainly 72% of residential buildings and 19% of small factories (*Figure 67*). Additional information specific to Kitakoujiya town is shown in *Figure 68*, *Figure 69*, *Table 45*, *Table 46* and *Table 47*. Other common information shared among the three towns are mentioned from *4.6.2 Modeling community system* to *4.6.5 Modeling power network component*. All the information is specific for August and forecasted daily power demand and the corresponding scheduling of daily power supply are shown in *Figure 70*.

Figure 64 Community and power distribution network layout of Kitakoujiya town case study

Figure 65 Street view of Kitakoujiya town (1)

Figure 66 Street view of Kitakoujiya town (2)

Case name	Kitakoujiya
Number of villages	2
Number of neighborhoods	39
Town area (km2)	0.30
Buildable area (km2)	0.27
Built area (km2)	0.21

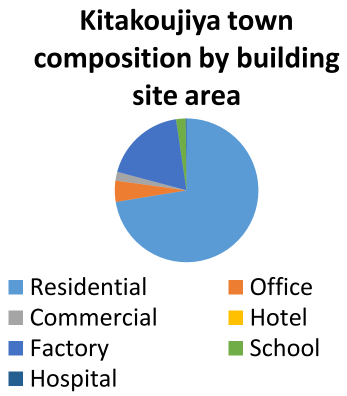


Figure 67 Profile of Kitakoujiya town and its composition by building type

Building type	Coefficient of BFA
House	2.5
Apartment	5
Office (Standard)	2
Office (OA)	2
Shop	2
Clinic	2
Hotel	4
Sports	2
Factory	2
Others	2
School	4
Hospital	2

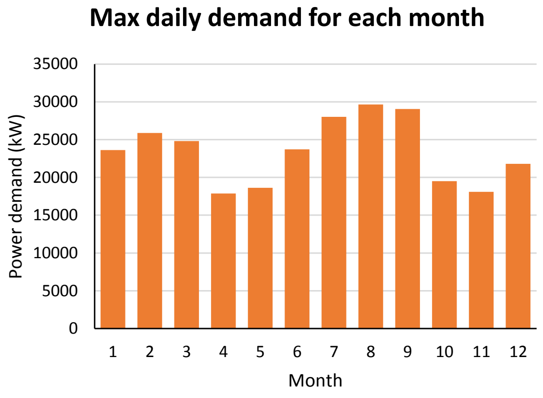


Figure 68 Coefficient of BFA of building types and estimated maximum daily demand for each month of Kitakoujiya town

Generation type	Capacity (kW)
Stable	31450.00
Intermittent	2987.61
Storage	8929.27
Total	43366.88

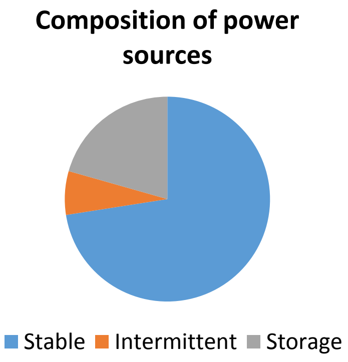


Figure 69 Composition of power sources in Kitakoujiya town by stable, intermittent and storage-based generations

Table 45 Profile of stable generation of Kitakoujiya town in August

Month	8					
Stable generation unit	Max power capacity (MW)	Max generation capacity (% of MW)	Min generation capacity (% of MW)	Ramp-up rate (% of MW/h)	Ramp-down rate (% of MW/h)	Cost (Yen/kWh)
Oil	7.40	100	5	80	-80	15.50
LNG+LPG	11.10	100	5	80	-80	6.50
Coal	5.55	100	10	50	-50	6.00
Nuclear	7.40	50	40	10	-10	5.50
Hydroelectric	3.70	100	10	100	-100	10.50

Table 46 Profile of intermittent (PV) generation of Kitakoujiya town

PV generation at village level	Total installed capacity (kW)
PV1	1283.48
PV2	1704.13

Table 47 Profile of storage-based generation of Toyosu town in August

Month	8				
Storage-based generation unit	Max storage capacity (kWh)	Max generation capacity (kW)	Ramp-up rate (kW/h)	Ramp-down rate (kW/h)	Cost (Yen/kWh)
PS hydroelectric	20350	1850	1850	-1850	42.80
Storage1	14980	2996	2996	-2996	30.00
Storage2	20416	4083	4083	-4083	30.00

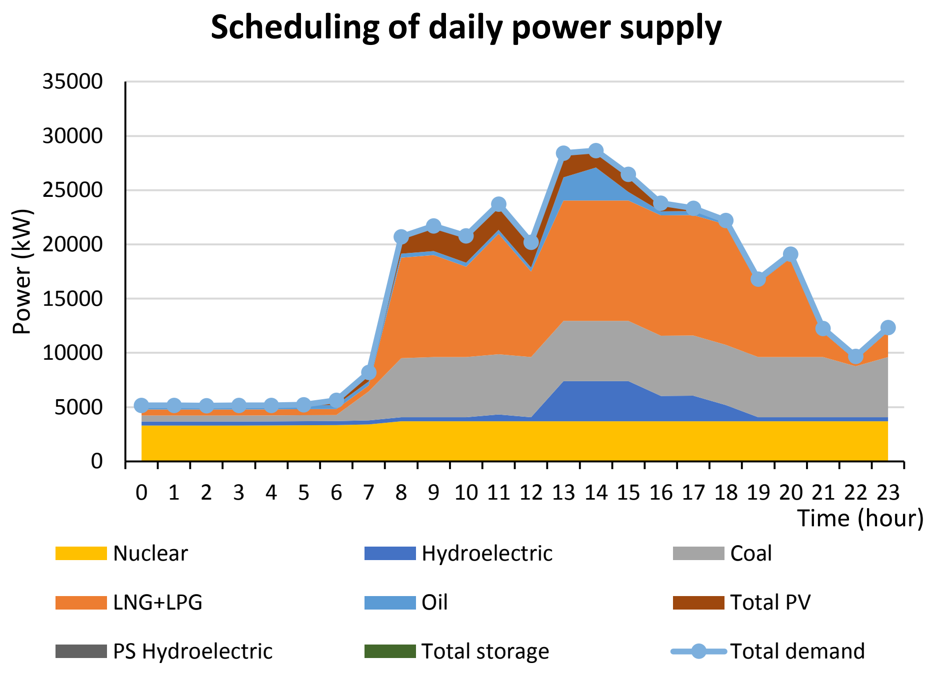


Figure 70 Scheduling of daily power supply to meet forecasted demand of Kitakoujiya town in August

5.2.5 Disturbance cases and scenarios

Energy resilience of a community system in this study is defined as the ability of a community depending on its own responsiveness and vulnerability to maintain its energy-dependent community functionality throughout any disturbances. It is necessary to simulate disturbance scenarios to community systems to examine their resilience performances. The forecasted daily demand and its corresponding power supply scheduling of each town-level community system have been modeled in the previous sections. In real world, there are numerous disturbances happening to a daily power operation that small disturbances are happening frequently and severely large ones are also happening but relatively less frequent and usually unpredictable. Disturbances can come in many forms (*Figure 18*, *page 34*) and cause various kinds of damages and dynamic changes to the operation of a power system (*Figure 19*, *page 35*). This study focuses on the disturbance effects to the power balance of community systems because any power imbalance can become a trigger to blackout event and that can cause serious problems to community members.

Disturbance scenarios in this study were simulated by changing the values of parameters of community system and its power components. Disturbances can be simulated in many ways, for example, the malfunction of power lines which may necessitate the use of bypass power lines, the abrupt change of actual power demand which results in bigger gap or error in forecasted demand, the deterioration or damages to the power components which affect the reliability and vulnerability, changes of weather conditions which may cause surplus or insufficiency of intermittent generation output and so on. However, the effects and damages caused by the disturbances to system performance are limited to those that are small-scale and short-term. Therefore it is assumed that the disturbed system can be recovered quickly. For the case study, four disturbance cases were prepared to simulate four different disturbance situations when decisions need to be made (*Table 48*). These disturbance cases were composed by 13 disturbance scenarios (*Table 49*). In order to avoid confusion, most of the disturbance scenarios were focused on the reduction of generation capacity of the bulk power supply which is the major concern during a disturbance event. In addition, service deterioration of some power components was also simulated to further demonstrate the usefulness of the assessment model.

Table 48 Four disturbance cases used in case study

*BAU: business as usual

Disturbance case	Disturbance scenarios	Case description	Decision maker
Case B	BAU, B1 to B5	• Reduction of all generation capacity due to disturbance such as earthquake. • Compare energy resilience of different towns.	• Energy suppliers. • Town planners.
Case C	BAU, C1, C2	• Closure of nuclear power generation. • Compare energy resilience of different towns.	• Policymakers. • Energy suppliers.
Case D	BAU, C2, D1, D2	• Reduction of all generation capacity due to disturbance with the complete closure of nuclear power generation. • Compare energy resilience of different towns.	• Town planners. • Policymakers. • Energy suppliers.
Case E	BAU, E1 to E3	• Service deterioration of system components.	• Energy suppliers.

Table 49 Description of each disturbance scenario

Disturbance scenario	Reduction of all generation capacity	Reduction of nuclear generation capacity	Service deterioration of some generation & network components	DR participation rate of residential users: -50%	Some power lines broken
BAU	-0%	-0%	×	×	×
B1	-10%	-10%	×	×	×
B2	-15%	-15%	×	×	×
B3	-25%	-25%	×	×	×
B4	-40%	-40%	×	×	×
B5	-50%	-50%	×	×	×
C1	-0%	-50%	×	×	×
C2	-0%	-100%	×	×	×
D1	-25%	-100%	×	×	×
D2	-40%	-100%	×	×	×
E1	-25%	-100%	○	×	×
E2	-25%	-100%	○	○	×
E3	-25%	-100%	○	○	○

Case B examines the energy resilience of community systems when the generation capacity behind the grid power is reduced due to disturbances such as earthquake, breakdown of generators and so on. It is important to note that while disturbance happen in Case B can be catastrophic disasters such as earthquake, the effects and damages to the community system are small-scale and short-term. Case B aims to demonstrate how town planners and energy suppliers can use this assessment model to make decisions and come up with constructive solutions that can help to sustain and improve the resilience performance. Since the Tohoku earthquake in 2011, Japanese people have raised concerns about the security of nuclear power plants and requested the country to shut down all the nuclear power generation. Case C and Case D are used to demonstrate how policymakers and energy suppliers can use this assessment model to support the process of decision making in this issue. Case C should represent the energy resilience performance of community systems when nuclear power generation is closed half (C1) and completely (C2). Case D is the extension of Case C that assesses energy resilience of community systems with all nuclear power plants closed experience reduced generation capacity of the bulk power. Case E is about the service deterioration of system components such as increased malfunctions of a generation or network unit, and reduced participation of demand users in the DR event. The case study will demonstrate how the decision makers can use this assessment model into good use and bring positive implications.

5.2.6 Demand response capacity

When some argue that DR should be made to improve efficiency of power operation, there are others who argue that human convenience such as comfort and productivity is at higher priority that DR should only be made when the available generation capacity is insufficient to ensure a safe and normal power operation. The author applies the latter standpoint in this study that users are only asked to reduce their power demand when the power supply is insufficient to ensure power balance.

Five levels of DR capacity were prepared to assist in studying its effect on energy resilience of communities (*Table 50*). An ideal or maximum level of available DR capacity was modeled by using the DR potentials (*Appendix 9*) and participation rates (*Table 32*) of all buildings types. This ideal level of available DR capacity is represented by DRC100. The situation of DRC1000 is when all community members are completely cooperative in reducing their power demands to the maximum possible level agreed by themselves as stated in the DR agreement. On the other case, DRC000 represents the situation where there is no reduction of power demand to be used as a supply resource to achieve power balance. This situation also represents the worst-level of available DR capacity or no implementation of DR program. Other levels are the interpolation between the ideal and zero levels.

Table 50 Five levels of demand response capacity used in case study

*Available demand response capacity is based on ideal level of demand response capacity

Level of available demand response capacity				
DRC100 (Ideal)	DRC075	DRC050	DRC025	DRC000 (Zero)
100%	75%	50%	25%	0%

It is important to note that DR capacity is dependent on the participation rate of community members in a DR event (Please refer to *4.6.3 Modeling power consumption component* and *Table 32*). However, this probability-based and randomized participation rate was made constant in every scenario in the analysis. Therefore, the effect of DR capacity in the analysis was independent by itself.

5.3 Results of case study

The results of resilience performance of the three towns under 13 disturbance scenarios are shown in *Table 51*, *Table 52* and *Table 53*. It is important to note that resilience performance is the results of the performance of all functionality indicators (power balance, demand users' convenience and cost of electric energy). The results of supporting performance represented by the attribute indicators will be presented in *5.4 Discussion of usefulness and implications* where relevant. Full sheets of assessment results are included from *Appendix 23* to *Appendix 40*. In addition, the general weightage assignment for each power component for the three towns is included from *Appendix 41* to *Appendix 43*.

Table 51 Resilience performance of Umegaoka town

Disturbance scenario	Level of available demand response capacity				
	DRC100	DRC075	DRC050	DRC025	DRC000
BAU	Resilient	Resilient	Resilient	Resilient	Resilient
B1	Resilient	Resilient	Resilient	Resilient	Unresilient
B2	Resilient	Resilient	Resilient	Unresilient	Unresilient
B3	Resilient	Resilient	Unresilient	Unresilient	Unresilient
B4	Resilient	Unresilient	Unresilient	Unresilient	Unresilient
B5	Unresilient	Unresilient	Unresilient	Unresilient	Unresilient
C1	Resilient	Resilient	Resilient	Resilient	Unresilient
C2	Resilient	Resilient	Resilient	Unresilient	Unresilient
D1	Resilient	Unresilient	Unresilient	Unresilient	Unresilient
D2	Unresilient	Unresilient	Unresilient	Unresilient	Unresilient
E1	Resilient	Unresilient	Unresilient	Unresilient	Unresilient
E2	Unresilient	Unresilient	Unresilient	Unresilient	Unresilient
E3	-	-	-	-	-

Table 52 Resilience performance of Toyosu town

Disturbance scenario	Level of available demand response capacity				
	DRC100	DRC075	DRC050	DRC025	DRC000
BAU	Resilient	Resilient	Resilient	Resilient	Resilient
B1	Resilient	Resilient	Resilient	Resilient	Resilient
B2	Resilient	Resilient	Resilient	Resilient	Resilient
B3	Resilient	Resilient	Resilient	Resilient	Resilient
B4	Resilient	Resilient	Resilient	Unresilient	Unresilient
B5	**Unresilient**	**Unresilient**	Unresilient	Unresilient	Unresilient
C1	Resilient	Resilient	Resilient	Resilient	Resilient
C2	Resilient	Resilient	Resilient	Resilient	Resilient
D1	Resilient	Resilient	Resilient	Resilient	Unresilient
D2	**Unresilient**	**Unresilient**	**Unresilient**	Unresilient	Unresilient
E1	Resilient	Resilient	Resilient	Resilient	Unresilient
E2	Resilient	Resilient	Resilient	Unresilient	Unresilient
E3	Resilient	Resilient	Resilient	Unresilient	Unresilient

Table 53 Resilience performance of Kitakoujiya town

Disturbance scenario	Level of available demand response capacity				
	DRC100	DRC075	DRC050	DRC025	DRC000
BAU	Resilient	Resilient	Resilient	Resilient	Resilient
B1	Resilient	Resilient	Resilient	Resilient	Resilient
B2	Resilient	Resilient	Resilient	Resilient	Resilient
B3	Resilient	Resilient	Resilient	Resilient	Resilient
B4	Resilient	Resilient	Resilient	Unresilient	Unresilient
B5	Resilient	Unresilient	Unresilient	Unresilient	Unresilient
C1	Resilient	Resilient	Resilient	Resilient	Resilient
C2	Resilient	Resilient	Resilient	Resilient	Resilient
D1	Resilient	Resilient	Resilient	Resilient	Unresilient
D2	Resilient	Resilient	Unresilient	Unresilient	Unresilient
E1	Resilient	Resilient	Resilient	Resilient	Unresilient
E2	Resilient	Resilient	Resilient	Resilient	Unresilient
E3	-	-	-	-	-

When a town has resilient performance, it means that the town manages to achieve power balance in its daily power operation, the users are satisfactory with the power supply service that support their activities, and the cost of the power operation is within acceptable range in a specific disturbance scenario. The grey boxes in the result tables represent unresilient performance when power balance cannot be achieved in the daily power operation. In the case where power balance is successful but if either users' convenience or cost of electric energy fails to perform within acceptable level, then the town in that specific disturbance scenario is also considered as unresilient too and this situation is shown as "**unresilient**". In the disturbance scenario B5 (DRC100 and DRC075) of Toyosu town, the cost of electric energy has exceeded the threshold value (Please refer to *5.4.1 Case B*) and thus the performances in those scenarios are **unresilient**. As mentioned earlier, Case C and Case D are the disturbance cases to assess changes of energy resilience performance when nuclear power generation is closed half and completely. In fact, Case D can also be used to compare with some disturbance scenarios of Case B to see the changes of resilience performance of towns with full closure of nuclear power generation experience additional reduction of generation capacity, where C1 is comparable with BAU, D1 with B3, and D2 with B4. For those cases, the black boxes in the result tables represent unresilient performance when power balance cannot be achieved in the daily power operation, and **unresilient** sign shows the cost of electric energy has exceeded the threshold value, for example, in disturbance scenario D2 (DRC100, DRC075 and DRC050) of Toyosu town.

Further discussion about the results will be given in the next section to demonstrate the usefulness of the proposed methodology to the decision makers in different disturbance cases and implications to the real practice. The results of the daily power operation, the power supply composition used to meet the demand and the amount of DR capacity used by each town in each disturbance scenario are given (from *Figure 71* to *Figure 78*) to provide a better information about the power operation and how each power generation unit and DR had performed. It can be seen that the daily power operations of Toyosu and Kitakoujiya towns in disturbance scenarios B1, B2, B3, C1 and C2 did not require any DR capacity to achieve power balance. The results for disturbance scenarios E1, E2 and E3 are not shown because the additional disturbances in those scenarios did not affect the daily power operation and the results are actually identical to the D1.

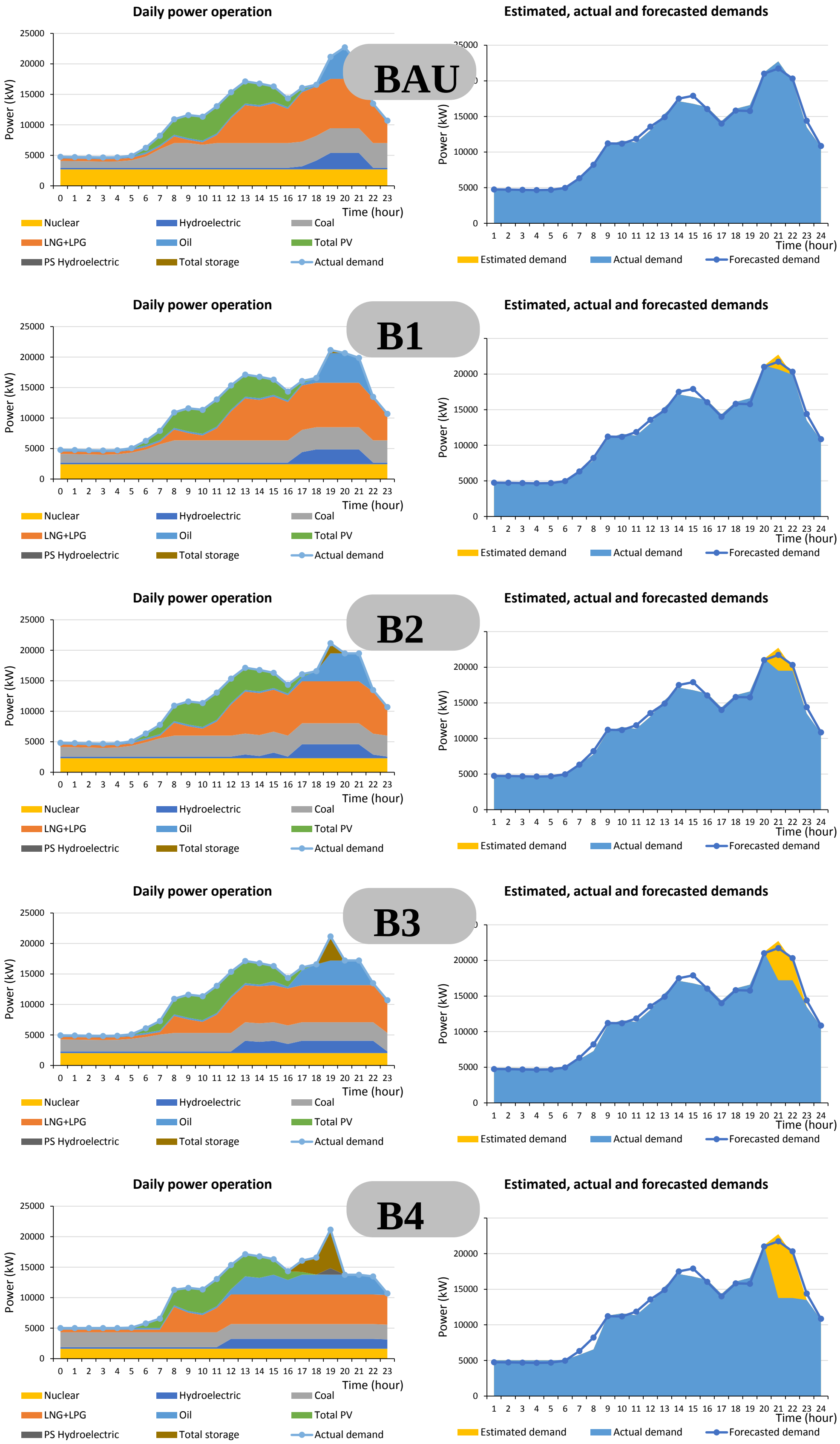
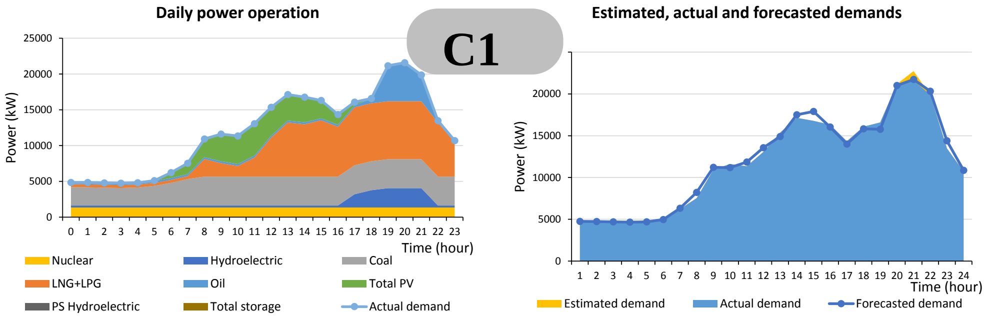


Figure 71 Performance of power generation units and demand response in a daily power operation of Umegaoka town (BAU, B1, B2, B3 and B4)

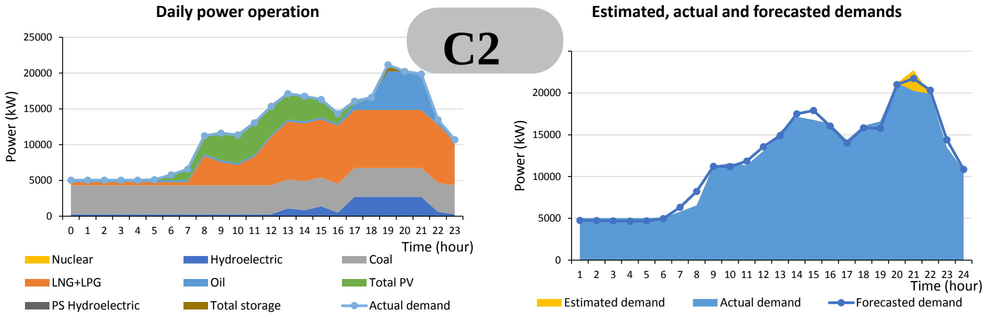
B5

Power balance was not achieved in any DRC level.
(Optimization failed)

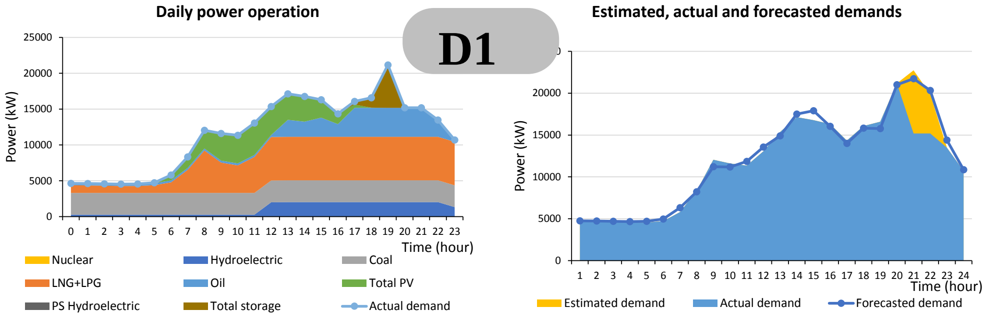
C1



C2



D1



D2

Power balance was not achieved in any DRC level.
(Optimization failed)

Figure 72 Performance of power generation units and demand response in a daily power operation of Umegaoka town (B5, C1, C2, D1 and D2)

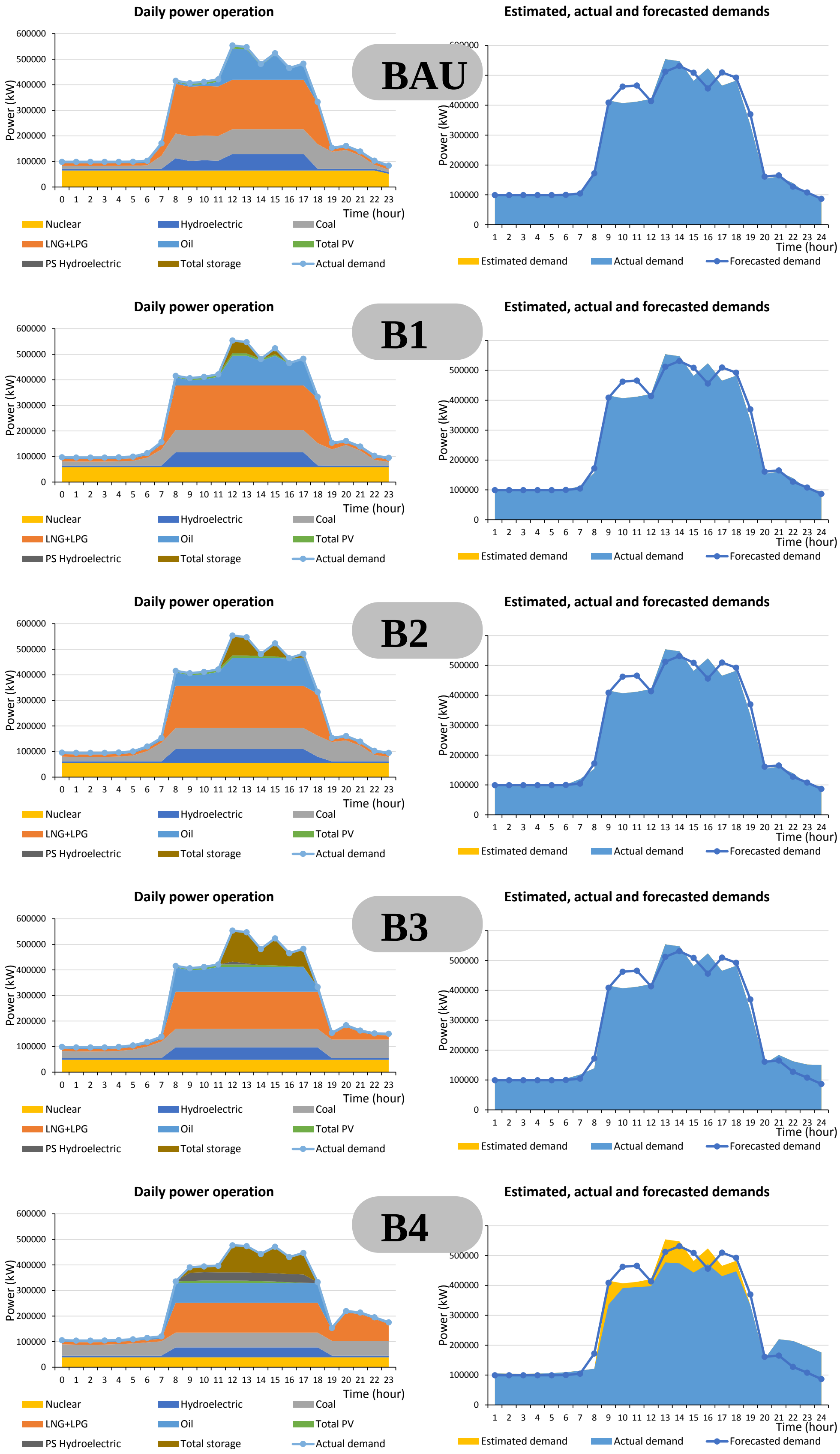


Figure 73 Performance of power generation units and demand response in a daily power operation of Toyosu town (BAU, B1, B2, B3 and B4)

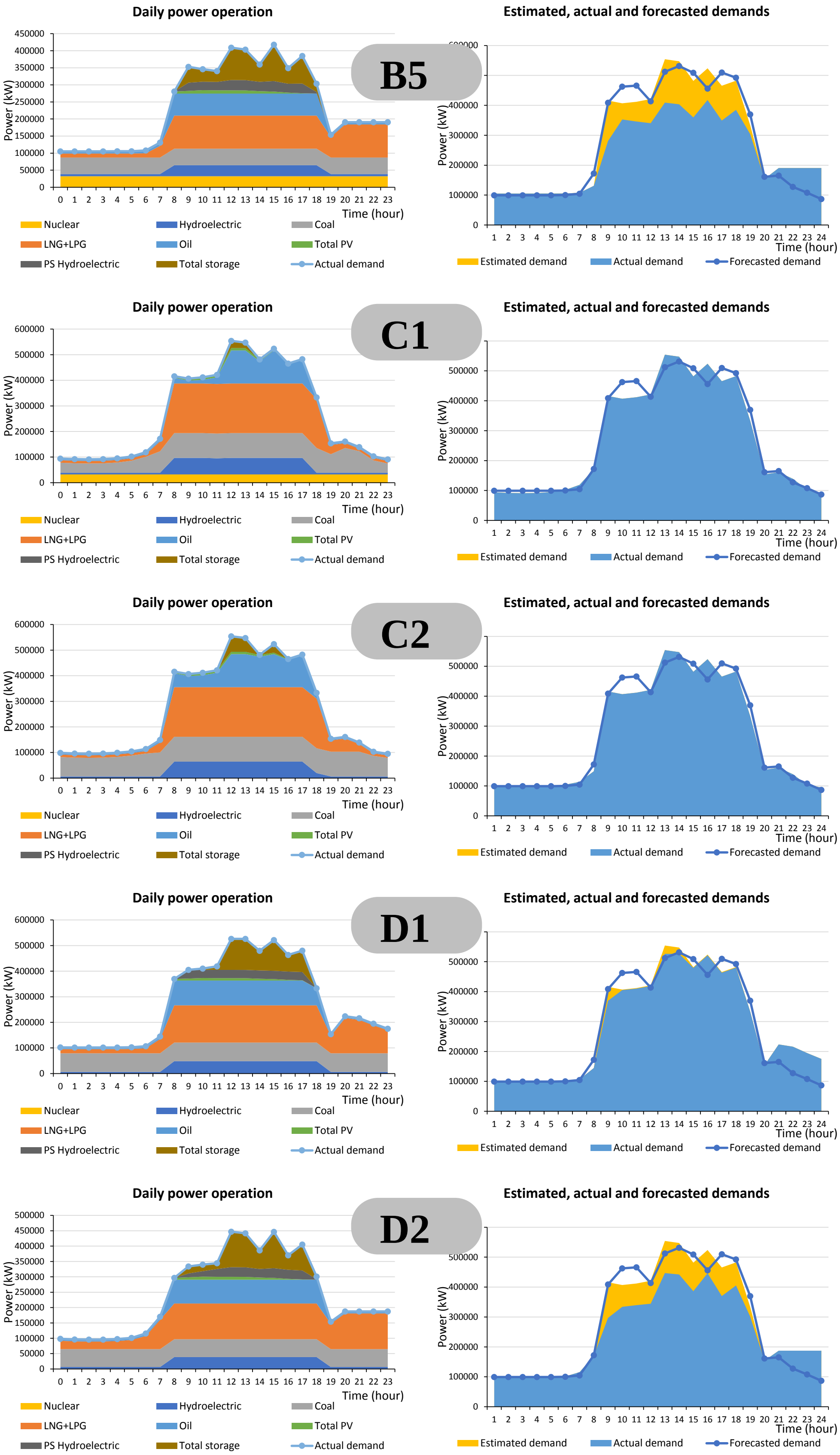


Figure 74 Performance of power generation units and demand response in a daily power operation of Toyosu town (B5, C1, C2, D1 and D2)

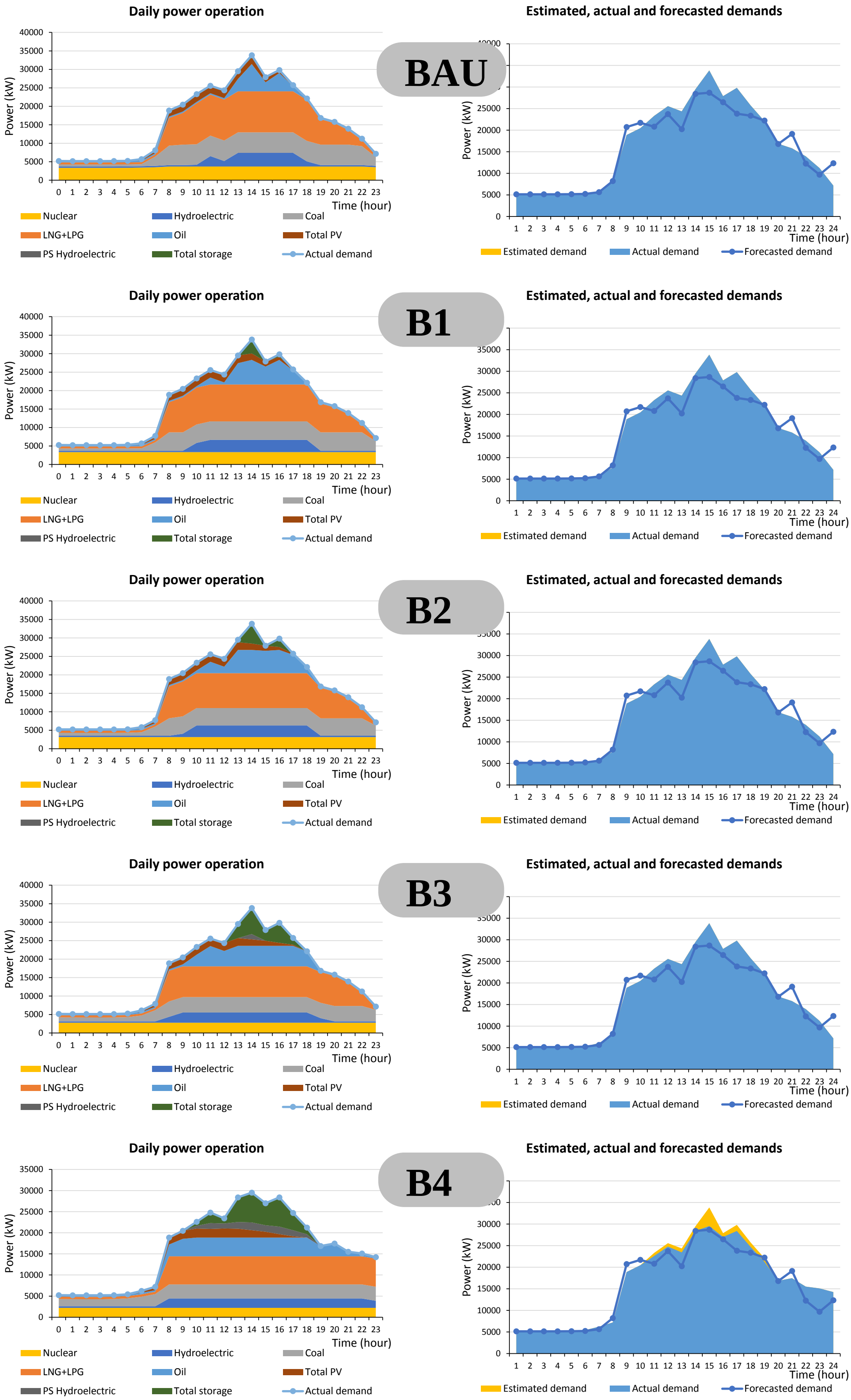


Figure 75 Performance of power generation units and demand response in a daily power operation of Kitakoujiya town (BAU, B1, B2, B3 and B4)

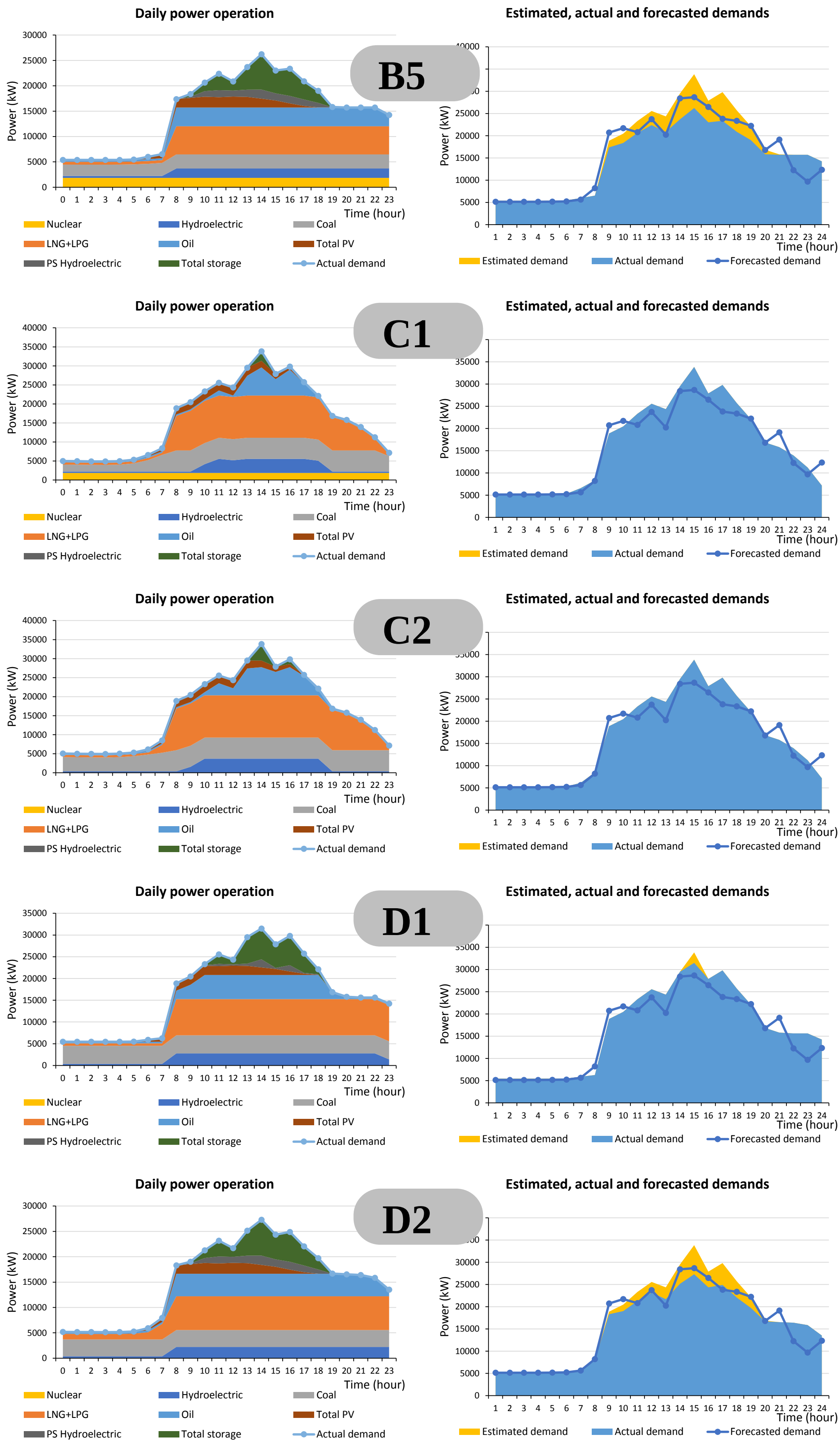


Figure 76 Performance of power generation units and demand response in a daily power operation of Kitakoujiya town (B5, C1, C2, D1 and D2)

5.4 Discussion of usefulness and implications

The case study results are used to demonstrate how decision makers can use the assessment model in the process of various decision makings through four disturbance cases. Case B is the main case used to discuss the core usage of this assessment model when used by energy suppliers and town planners. The other cases such as Case C, Case D and Case D are used to demonstrate additional usage of this assessment model in different situations. Discussion of each case will also include the implications of using this assessment model to the decision makers in their practice or operation and the bottom-level users, namely the community members.

It is important to note that the assessment results are compared to threshold values which are arbitrarily selected by the author for the demonstration purpose. Objective and practical principles on selecting indicator thresholds are presented in *4.1.4 Data and threshold of assessment*.

5.4.1 Case B

Case B can be a good case to demonstrate how energy suppliers can use the assessment model to support decision making. Nowadays, when a power system is becoming unstable, the usual practice is that energy suppliers will request the users to reduce their power demand as much as possible. Sometimes the amount of demand reduction is a lot more than the required amount to keep the power system stable. Unnecessary demand reduction deters human activities. However, the suppliers have to do it this way because currently not every building is equipped with building energy management system (BEMS) that the suppliers are unable to ascertain the actual demand reduction from the users.

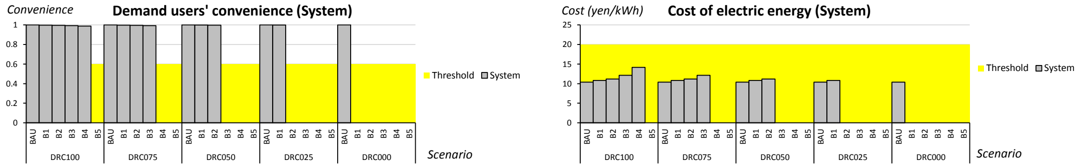
When BEMS is more widely adopted by the users and the suppliers manage to get hold of data and information about how users are acting in DR events, then the suppliers can use this assessment model to decide the required amount of demand reduction to request from the users. For example, the column of DRC100 in *Table 54* represent the current practice which the suppliers are doing to get as much demand reduction as possible from the users, whereas in fact the suppliers of Umegaoka town can decide to request the users to at least reduce 25% of their demand if the disturbance scenario is equal to B1, or 75% if it is B3. Users can then reduce the required amount of power demand based on the visualized consumption information from the BEMS. In this way, the assessment result can help to make the DR program to be more efficient that no unnecessary demand reduction has to happen. This situation also can help to create good relationship between the energy suppliers and the users because the users understand that the suppliers are professionally doing their jobs to keep the power system stable without overlooking the needs or performance at the bottom level. Based on the assessment results, the suppliers can also design and offer effective DR programs to the demand users.

Table 54 Comparison of resilience performance of three towns in Case B

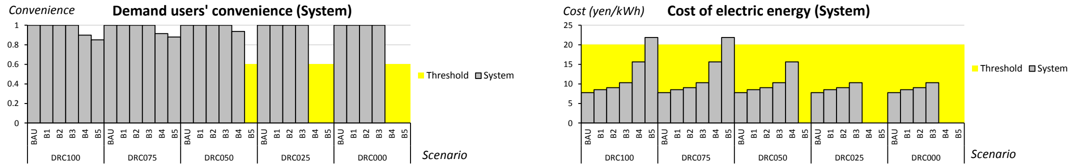
Town	Disturbance scenario	Level of available demand response capacity				
		DRC100	DRC075	DRC050	DRC025	DRC000
Umegaoka	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	B1	Resilient	Resilient	Resilient	Resilient	Unresilient
	B2	Resilient	Resilient	Resilient	Unresilient	Unresilient
	B3	Resilient	Resilient	Unresilient	Unresilient	Unresilient
	B4	Resilient	Unresilient	Unresilient	Unresilient	Unresilient
	B5	Unresilient	Unresilient	Unresilient	Unresilient	Unresilient
Toyosu	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	B1	Resilient	Resilient	Resilient	Resilient	Resilient
	B2	Resilient	Resilient	Resilient	Resilient	Resilient
	B3	Resilient	Resilient	Resilient	Resilient	Resilient
	B4	Resilient	Resilient	Resilient	Unresilient	Unresilient
	B5	**Unresilient**	**Unresilient**	Unresilient	Unresilient	Unresilient
Kitakoujiya	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	B1	Resilient	Resilient	Resilient	Resilient	Resilient
	B2	Resilient	Resilient	Resilient	Resilient	Resilient
	B3	Resilient	Resilient	Resilient	Resilient	Resilient
	B4	Resilient	Resilient	Resilient	Unresilient	Unresilient
	B5	Resilient	Unresilient	Unresilient	Unresilient	Unresilient

A benefit of DR is to allow the energy suppliers to delay the expansion of generation capacity which involves large investment capital to build new power plants. However, a resilient community system should require not only a stable power operation but the community activities and functions must be maintained above acceptable level as well. Therefore, a DR program should not be used as a means to avoid building new generation facilities by making the users suffer. Instead, the suppliers should use this assessment model to support them in making decision about the right timing to start planning for generation expansion. For example in *Table 54*, Toyosu town actually managed to achieve power balance in the B5 scenario with DRC100 and DRC075 but the cost of operation in this two scenarios exceeded the threshold value (*Figure 77*), which is why Toyosu town was considered as unresilient. This is the time when the suppliers should plan for new generation expansion so that other community-based functionalities can be maintained above acceptable level and a safe degree of resilience is ensured. The assessment methodology proposed here can be based on to develop resilient operation plans and strategies that meet the ends of both sides.

Performance of supporting functionality indicators of Umegaoka town



Performance of supporting functionality indicators of Toyosu town



Performance of supporting functionality indicators of Kitakoujiya town

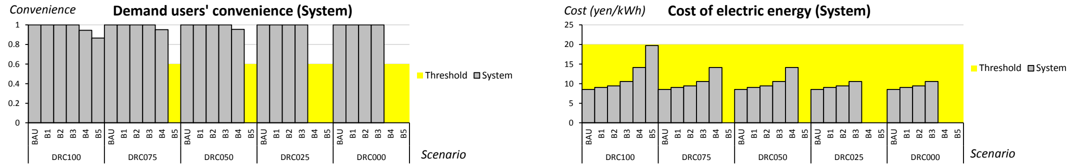


Figure 77 Performance of supporting functionality indicators of three towns in Case B

Case B can also be a good case to demonstrate how town planners can use the assessment model to support the decision-making process when planning and designing a new town. If a town planner has to choose a town design among Umegaoka, Toyosu and Kitakoujiya towns, based on the overall resilience performance, the town planner should choose Kitakoujiya town because it has the most resilient performance (*Table 54*). Besides comparing the overall resilience performance, there are many other potential methods to use the assessment results to make comparison. For example, comparison of resilience performance of towns subject to earthquake disturbance can be made. By assuming that blackout probability is correlated to the reduction of generation capacity at the supply side, the estimated blackout probability in *Table 55* is used to indicate the estimated reduction of generation capacity for Umegaoka and Toyosu towns which are each located in Setagaya and Koutou districts respectively. The results of resilience performance of the two towns if Northern Tokyo Bay earthquake of M6.9 and M7.3 occur are shown in

Table 56. In the case of earthquake M6.9, the equivalent disturbance scenario experienced by Umegaoka town is B1 whereas Toyosu town is B3, and in the case of earthquake M7.3, Umegaoka town is B2 and Toyosu town is B4. By considering such situation, Toyosu town is considered to be more resilient than Umegaoka town. This information is helpful to the town planners as an input to decide the choice of town design.

Table 55 Estimated blackout probability of districts in Tokyo during Northern Tokyo Bay earthquake [東京都防災会議地震部会, 2006]

Estimated blackout probability (%)	Northern Tokyo Bay earthquake	
	M6.9	M7.3
Tokyo prefecture	9.2	16.9
All districts	12.9	22.9
Setagaya	8.8	16.9
Koutou	26.2	38.2
Sumida (max)	35.9	48.6
Chiyoda (min)	2.0	6.1

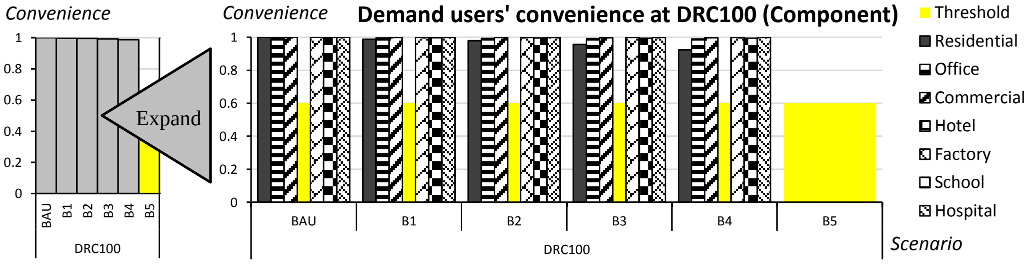
Table 56 Resilience performance of Umegaoka and Toyosu towns under earthquake disturbance

Earthquake magnitude	Town	Disturbance scenario	DRC100	DRC075	DRC050	DRC025	DRC000
M6.9	Umegaoka	B1	Resilient	Resilient	Resilient	Resilient	Unresilient
M6.9	Toyosu	B3	Resilient	Resilient	Resilient	Resilient	Resilient
M7.3	Umegaoka	B2	Resilient	Resilient	Resilient	Unresilient	Unresilient
M7.3	Toyosu	B4	Resilient	Resilient	Resilient	Unresilient	Unresilient

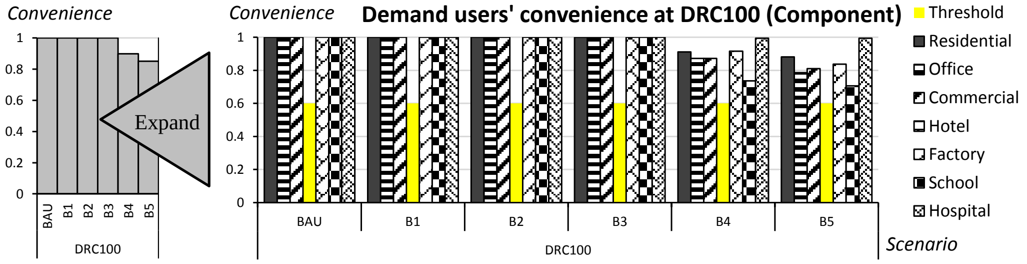
The demonstration so far has been about using the aggregated or integrated assessment results which represent the overall community system performance. When and where usage context becomes necessary, the assessment results of system components can be used alone or together with the assessment results of the whole system to support decision making. *Figure 78* shows that the integrated results of demand users' convenience in the three towns with DRC100 are broken into bottom-level performance. If a town planner were to plan for a town in a location where the worst disturbance scenario that could happen is B4 and there is a working plan to get the town people to contribute all their DR capacity when necessary, then based on the result, the town planner should choose Umegaoka town design because of better performance in users' convenience. By looking into bottom-level performance, a decision maker can better understand which component unit is performing well and if there is any component unit underperforming. Bottom-up assessment actually enables decision makers to improve the overall system performance from the bottom level without compromising any bottom-level component.

From the discussion of Case B, it is clear that in the discourse of resilience performance, the context of disturbance scenario must be presented as well. As a result, the resilience performance of a town is not a permanent state but rather a dynamic performance which is affected by any relevant disturbance. If a general resilience performance of a system must be established, several analysis and assessments using methods such as Monte Carlo simulation to cover various disturbance scenarios especially the extreme ones can be made.

Bottom-level performance of supporting functionality indicators of Umegaoka town



Bottom-level performance of supporting functionality indicators of Toyosu town



Bottom-level performance of supporting functionality indicators of Kitakoujiya town

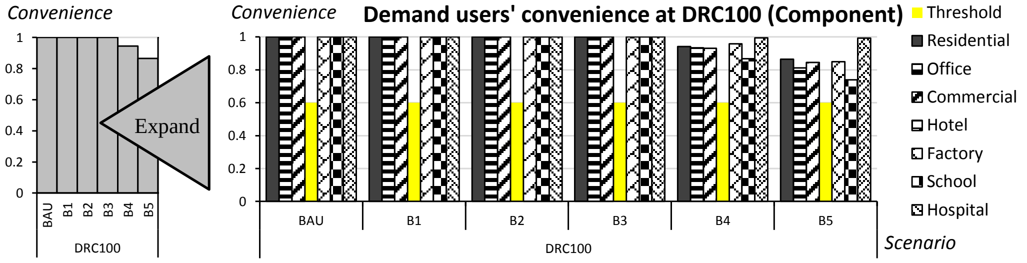


Figure 78 Bottom-level performance of supporting functionality indicators of three towns

5.4.2 Case C and Case D

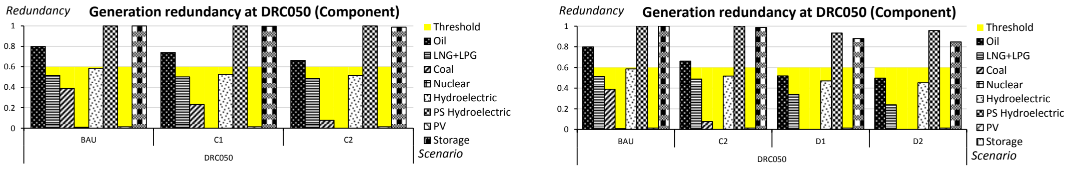
Case C and Case D are related to the issue of shutting down or closing nuclear power plants. Nuclear power generation has been a controversial issue everywhere in the world especially in Japan. The Fukushima accident caused by the Tohoku earthquake happened in year 2011 has resulted in Japanese society requesting for complete closure of nuclear power plants in the country. Closure of nuclear power plant is a disturbance situation to the power system as represented by Case C. Reduced generation capacity of bulk power when nuclear power generation is completely closed is the disturbance situation represented by Case D. Assessment results of Case C and Case D should provide useful information to policymakers to decide if it is safe or resilient or not to shut down all the nuclear power generation with the consideration of some disturbance scenarios. *Table 57* and *Table 58* show the assessment results of energy resilience performance of the three towns in Case C and Case D. When it is within expectation that the resilience performance will be lower or worse due to the closure of nuclear power generation, the assessment results can provide further information about how much worse the performance has become and the required DR capacity to sustain a resilient performance when possible (just like the usefulness mentioned in Case B). These information are useful to the policymakers to decide if closing the nuclear power plants is feasible option or not. It is important to note again that the analysis and assessment results do not represent the reality because they are only used to demonstrate the usefulness of the proposed assessment methodology in decision-making process. However, when the bottom-up assessment model is developed into a practical model, it can be used to make further assessment of bottom-level performance to see how closure of nuclear power plants affects the other generation types. From *Figure 79*, it can be observed that redundancy performance of coal-based generation usually decreases more than the other types of generation in almost all the disturbance scenarios. This situation is best possibly explained by the fact that both coal-based and nuclear-based generations are usually used as the baseline generation and therefore the closure of nuclear power generation can result in the coal-based power generation having to fill up or replace the lost generation capacity more than any other types of generation have to. Decision makers can make further analysis and assessment to find out whether the increase dependence on coal-based generation can meet the requirements of power production or not, for example, the requirement of carbon emission, production cost and so on. The decisions made here can have direct and indirect implications to the users in terms of cost of electric energy and environmental quality.

Table 57 Comparison of resilience performance of three towns in Case C

Town	Disturbance scenario	Level of available demand response capacity				
		DRC100	DRC075	DRC050	DRC025	DRC000
Umegaoka	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	C1	Resilient	Resilient	Resilient	Resilient	Unresilient
	C2	Resilient	Resilient	Resilient	Unresilient	Unresilient
Toyosu	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	C1	Resilient	Resilient	Resilient	Resilient	Resilient
	C2	Resilient	Resilient	Resilient	Resilient	Resilient
Kitakoujiya	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	C1	Resilient	Resilient	Resilient	Resilient	Resilient
	C2	Resilient	Resilient	Resilient	Resilient	Resilient

Table 58 Comparison of resilience performance of three towns in Case D

Town	Disturbance scenario	Level of available demand response capacity				
		DRC100	DRC075	DRC050	DRC025	DRC000
Umegaoka	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	C2	Resilient	Resilient	Resilient	Unresilient	Unresilient
	D1	Resilient	Unresilient	Unresilient	Unresilient	Unresilient
	D2	Unresilient	Unresilient	Unresilient	Unresilient	Unresilient
Toyosu	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	C2	Resilient	Resilient	Resilient	Resilient	Resilient
	D1	Resilient	Resilient	Resilient	Resilient	Unresilient
	D2	**Unresilient**	**Unresilient**	**Unresilient**	Unresilient	Unresilient
Kitakoujiya	BAU	Resilient	Resilient	Resilient	Resilient	Resilient
	C2	Resilient	Resilient	Resilient	Resilient	Resilient
	D1	Resilient	Resilient	Resilient	Resilient	Unresilient
	D2	Resilient	Resilient	Unresilient	Unresilient	Unresilient



Case C

Case D

Figure 79 Redundancy performance of generation components of Toyosu town for Case C and Case D

5.4.3 Case E

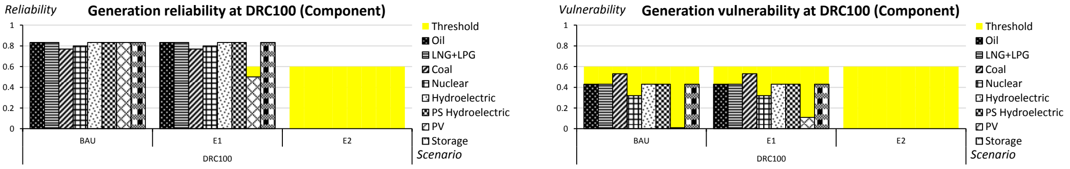
Case E is designed to demonstrate how energy suppliers can use this assessment model to detect or investigate problems of the system and its components, and then to support the decision-making process to solve the problem. Instead of resilience performance, this Case E focuses on demonstrating how to make use of the results of attribute indicators which represent the supporting performance of a system. In disturbance scenario E1, service deterioration is focused on the generation and network components in the three towns (*Table 59*). On the other hand, the participation rate in DR event of residential users for the three down is dropped to 50% in disturbance scenario E2.

Table 59 Service deterioration of generation and network components in three towns

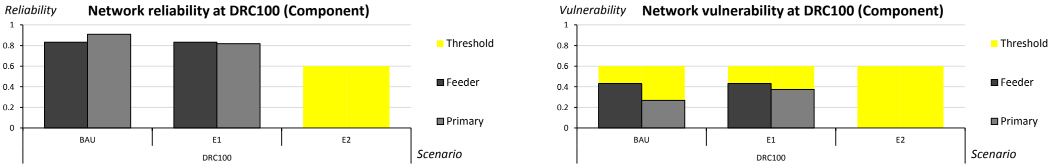
Town	Generation component	Network component
Umegaoka	PV generation	Primary network line
Toyosu	LNG generation	Distribution feeder line
Kitakoujiya	PV generation	Primary network line

By comparing the results of reliability performance in scenario E1 to scenario BAU for the three towns (graphs at left side in *Figure 80*, *Figure 81* and *Figure 82*), we can see that there are obvious drop in the reliability performance of the PV (photovoltaic) generation and primary network for the Umegaoka and Kitakoujiya town, and drop in the reliability performance of the LNG generation and distribution feeder network for the Toyosu town. This shows that the assessment model can correctly reflect changes of performance, which in this case is the reliability performance. This is one of the advantages of using bottom-up approach in assessment that performance of bottom-level components can be assessed and located. When reliability performance has changed, this will affect the vulnerability performance of the relevant components as well (graphs at right side in *Figure 80*, *Figure 81* and *Figure 82*). On the other hand, by comparing the results of reliability performance in scenario E2 to scenario BAU for the three towns in the same set of figures, we can see that the reliability performance of the residential building types has dropped for Toyosu and Kitakoujiya towns (Result of reliability performance for Umegaoka town is unavailable due to unresilient performance that it failed to achieve power balance).

Reliaiblity and vulnerability of generation component



Reliaiblity and vulnerability of network component



Reliaiblity and vulnerability of consumption component

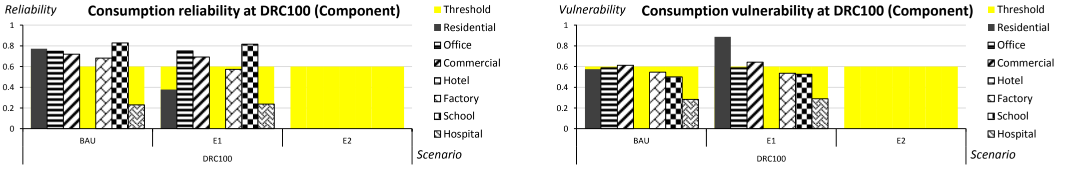


Figure 80 Reliability and vulnerability performance of generation, network and consumption components of Umegaoka town in Case E

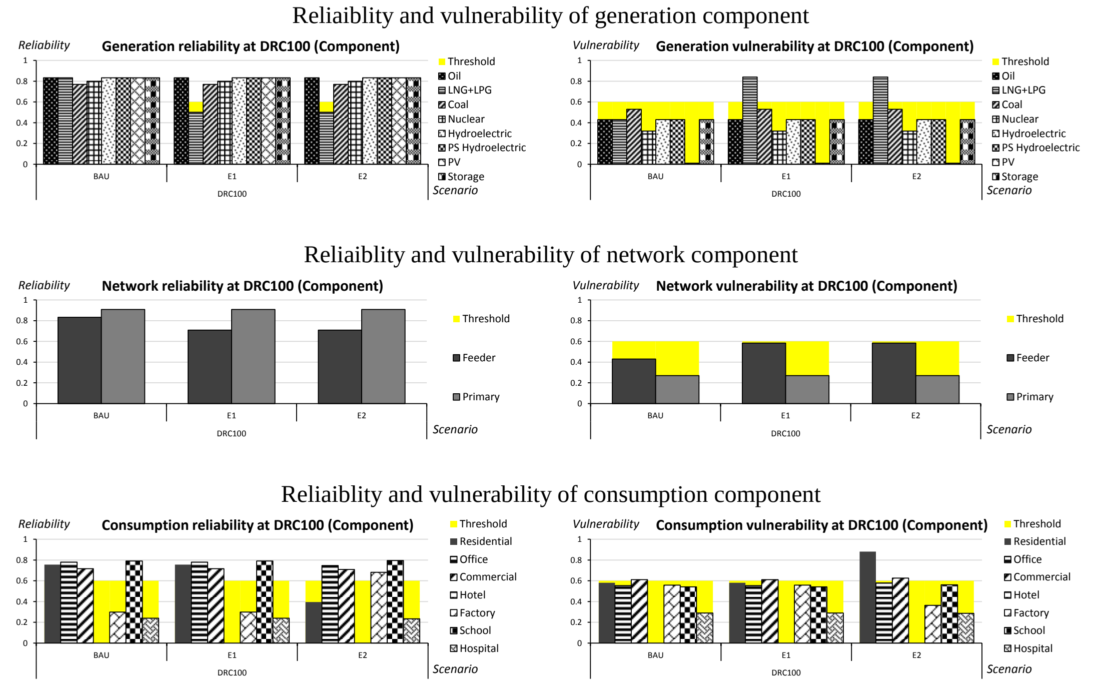


Figure 81 Reliability and vulnerability performance of generation, network and consumption components of Toyosu town in Case E

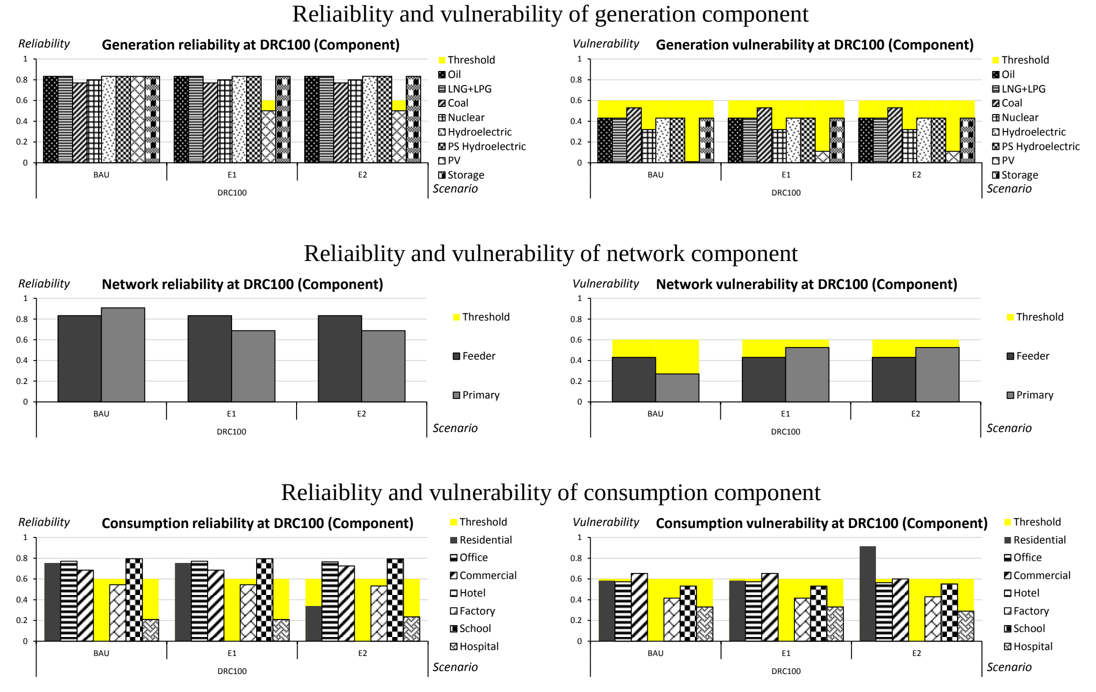


Figure 82 Reliability and vulnerability performance of generation, network and consumption components of Kitakoujiya town in Case E

When energy suppliers find out the problem of reduced reliability or increased vulnerability in the system components from the assessment results, they can start to investigate further into the cause of the problem. According to the resilience definitions of generation and network components in this study (*Eq. 11*) and (*Eq. 13*), service deterioration of components means that the MTBF of the relevant components has become smaller (or shorter) and those components are now experiencing failures more frequently than before. This decrease in reliability can be caused by various reasons such as the wears and tears, physical damages and any software-related problems. Investigation should be made to find out the causes of the problem and solutions to restore and improve the reliability of those components such as repairing or replacing of those components must be made. On the other hand, the reduced participation rate of residential users in the DR event can pose as a risk to the energy resilience of a community system especially in the event of large disturbance. The energy suppliers should assess the corresponding vulnerability caused by this reduced reliability performance from this consumption component. If the vulnerability level is unacceptable then actions must be taken to restore or improve the reliability performance.

It is important to note that the performance of reliability and vulnerability are only supporting performance of a system but they are useful as an indirect indicators to provide foresight about the future resilience of a community system.

5.4.4 Optimization of energy resilience

This section aims to demonstrate the capability of the proposed assessment methodology to assist in optimization of energy resilience of communities. The analysis results have shown that as the disturbance effect gets more severe the case-study towns start to lose their resilience capacity and they failed to achieve power balance especially for the Umegaoka case where no power balance could be achieved in any level of available DR capacity in the disturbance scenario B5. This condition shows that the constant parameters of the towns and their power components have become restraints to resilience performance that one or more of those parameters should be changed or improved to achieve optimization of energy resilience.

Each town has different composition and problems of resilience performance. For the case of Umegaoka town which is highly composed by residential buildings, the problem is caused by high power demand in the night time when most people are at home and consuming electric energy. The town composition of Toyosu and Kitakoujiya towns are different but their overall town demand patterns are quite similar to an extent that their peak demands happen during day time. There are numerous ways to optimize a power operation but this study only focuses on demonstrating optimization by using the possible decision variables identified in this study (*Table 29*). The optimization results of Umegaoka and Kitakoujiya cases are shown in *Table 60* and

Table 61. The bolded “**OK**” in shaded cell shows the improvement of resilience performance which was previously failed to achieve power balance before optimization.

Table 60 Results of power balance of Umegaoka town after optimization

Disturbance scenario	Level of available demand response capacity				
	DRC100	DRC075	DRC050	DRC025	DRC000
B5	**OK**	**OK**	Unresilient	Unresilient	Unresilient

Table 61 Results of power balance of Kitakoujiya town after optimization

Disturbance scenario	Level of available demand response capacity				
	DRC100	DRC075	DRC050	DRC025	DRC000
B5	OK	**OK**	**OK**	**OK**	Unresilient

In the case of Umegaoka town, battery storages within the town have been modeled to discharge (provide power supply) from 9am to 8pm and charge (consume power supply) from 8pm to 9am of the next day. The optimization was made by extending the discharging time to mid night 12am to overcome insufficient power capacity in the night time. Kitakoujiya case has been selected to represent the optimization of Toyosu town and itself because both towns have similar problem of power insufficiency in the day time. One possible solution can be to install more solar generation in those towns to increase power supply during day time. The installation of solar panels in the towns was set at 10% in the previous analysis and it has been manipulated to optimize the resilience performance. However, optimization by increasing solar generation gave very limited improved performance that even when solar generation was set to maximum level only a few scenario analysis showed better changes. In order to further optimize the resilience performance, battery storage capacity was changed from 10% to 20% in addition to maximum level of solar generation installation. The analysis results showed much better improvement. This situation shows that even though there are decision variables from supply and demand sides but each decision variables have different sensitivity or impact on the energy resilience. Therefore optimization of power operation should involve all key stakeholders from both supply and demand sides so that the desired outcomes can be optimized with acceptable tradeoffs on both sides.

By comparing the results before and after optimization, it is understood that the required DR capacity to achieve power balance for each scenario was reduced. The reduction is a sign of improved demand users’ convenience as a result of extended battery discharging time and increased solar generation capacity and battery storage capacity. When those optimization certainly induces other changes such as investment cost and the power scheduling solution, the optimization has demonstrated the applicability of the proposed assessment method to be used to assist optimization of energy resilience of communities.

5.4.5 Other discussion

It is necessary to discuss the pros and cons of using DR capacity as the decision variable to study energy resilience. The impression of the usefulness of DR can be quite different depending on the way how it is implemented. The first implementation approach, which is applied in this study, users' convenience (comfort) is of higher priority than efficient or economic power operation that DR is only used if the supply-side power resources are insufficient. Under such implementation principle, the importance of DR is limited to fill up the insufficiency of power supply that it is hard to exhibit the advantage or disadvantage of having a little or abundant of DR capacity. This is why the performances of supporting functionality indicators are equal for all levels of available DR capacity in a given disturbance scenario. If different implementation of DR is applied that users' convenience can be reduced to certain level in order to achieve more efficient and economic power operation, then the possible ways of using DR in a power operation will become more flexible. This changes can affect the overall analysis results and the performance of supporting functionality indicators in a given disturbance scenario is expected to vary with different levels of available DR capacity. While the advantage of having more DR capacity is not obvious for *a given disturbance scenario* by using the first implementation approach of DR, the advantage becomes more apparent when system performance in *different disturbance scenarios* is considered.

This study also reveals the fact that advanced technology and exchange of information between supply and demand sides are essential in ensuring the success of DR. Advanced technology is necessary to automate DR so that every response can be executed in real-time (at the timescale of 30 minutes or an hour) to reduce uncertainties or any latency problem during the operation. When the supply-side operators or DR aggregators have collected and received large information samples of users' energy use behavior and DR participation behavior, they can derive statistically significant information useful to design DR programs which can complement power operation and improve supply-side strategy planning capabilities.

5.5 Limitations

The largest limitation or weakness of this study is that the proposed methodology is limited to assess functionality performance when a system is resilient in terms of power balance but not when the system is unresilient (power imbalance). Assessing performance during an unresilient state is a very significant but complicated and dynamic issue which becomes much more difficult when the performance during both resilient and unresilient states need to be assessed together. This study goes as far as assessing and discussing how DR capacity can keep a system performance within normal or resilient states but does not discuss in great details about system performance during unresilient state.

As mentioned earlier, the choice of this study to implement DR only when the power system is becoming unstable can be a limitation because it poses a limit to the flexible use of DR. In addition, this study assumes that pricing plan or fluctuation in all disturbance scenarios is the result of market demand and supply rather than a strategy purposely imposed to restrict power consumption. By doing so, the DR capacity or demand reduction considered in this study is all come from the reduction made when the users fulfil the DR request from the suppliers. The dynamics (reduction, increase and shift) of demand under the effect of pricing plan are not considered in detail. These dynamics are considered as already embedded into the forecasted demand which is based on historical data. However, this simplification can be a limitation to reflect the reality condition.

Also, the analysis of power operation was made in a stationary manner rather than dynamic. In fact, sometimes the power demand after a DR event can increase because the demand reduced could be just a shift of power consumption at later time. However, the analysis did not consider such dynamic condition which may increase the complexity of the discussion and that becomes another limitation of this study.

Chapter 6

Conclusion and recommendation

This chapter concludes this study by reporting the achievement extent of this study made in response to research aim, research questions and generated hypotheses. In the end, recommendation of future studies is given.

6.1 Conclusion

6.1.1 In response to research aim and research questions

All of the five research objectives have been accomplished that the process and results have been reported in this thesis. Overall, the author proposed a methodology to develop a model specific to assess energy resilience of community systems. The usefulness and implications of the proposed methodology were demonstrated through simulation-based case study. Accomplishing the research objectives was a means to achieve the research aim and helped to answer the research questions in this study (*Figure 83*). The answers to the research questions are as follows.

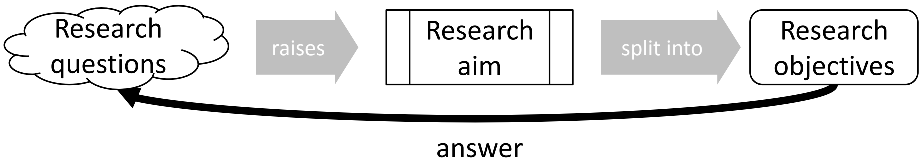


Figure 83 Research questions answered through achieving research objectives

What constitutes resilience?

In this study, the important elements constitute resilience are the functionality, responsiveness, disturbance and vulnerability. This answer is mainly the output from the analysis of resilience definition explained in *3.3 Definition of resilience*. The author claims in this study that resilience performance is determined by system functionality performance which is different than the usual understanding of resilience as resistance capacity or recovery rapidity of a system.

What in a community system are considered?

Under the reductionistic thinking and bottom-up approach, not only demand response (DR) capacity but other relevant power components (generation & network) are also considered when assessing the resilience performance of a community system. This is mainly explained in *4.1.3 Scale and system boundary of assessment* and *4.4 Concept component*.

How to assess energy resilience of a community system?

The author first proposed a methodology and then developed a model based on the proposed methodology to make case study to assess energy resilience of community systems. Explanation of the methodology proposal and model development are covered in *Chapter 3* and *Chapter 4*.

6.1.2 In response to generated hypotheses

The results of case study were used to check the generated hypotheses of this study. The first generated hypothesis is found to be conditionally true that a community with more DR capacity is more resilient because DR capacity can be used as virtual power supply source to achieve power balance. However, if the functions chosen to represent the resilience performance of a system were against or neutral to the effect of DR capacity, then this first hypothesis may become unsupported.

By looking at each town composition by building types, the Toyosu town composition is relatively more uniform than the others. As the results showed that Kitakoujiya town is more resilient than Toyosu town in most disturbance scenarios, therefore this study cannot support the second generated hypothesis. Again, this is related to the choice of functions selected as the indicator of resilience performance. In addition, the town composition by building area may not be a good correlative factor to resilience performance especially when the buildings in one town are mostly constituted by high-rise building whereas the other is not.

6.1.3 Final conclusion

This study has attempted to look into energy performance from the perspective of the resilience concept and demonstrated that the resilience concept is very applicable in this study context. By using the resilience concept, not only system performance under disturbance challenges becomes the focus of assessment, the alternative proposed resilience definition which concentrates on functionality consideration can provide a platform to encourage harmonization of global performance between the supply and demand sides so that positive relationship between energy suppliers and end-users can be created. In summary, there are two major emphases in this study: the first is the alternative understanding that resilience performance can be determined by functionality performance of a system, and the second is the global consideration of the interests from both supply and demand sides when performing any energy study and practice.

As the application of resilience concept in the field of architecture and Japanese power industry is only at the starting stage that the role of this study is to serve as an exploratory study to propose and demonstrate useful methodology. Therefore, the analysis in this study is only for demonstration purpose that the analysis results cannot be used to establish any statistically significant relationships between DR capacity and energy resilience. However, the author hopes that this work can stimulate more similar studies. When this study topic becomes more established in the future, this work can become reference and comparison material to other studies for verification and validation purpose.

6.2 Recommendation for future study

This study only represent an early and exploratory work of resilience study in the area of energy use of architecture that there is spacious room for improvement. The author recommends the following three future studies:

- Similar study can be made by implementing DR in a way to achieve more efficient and economic power operation besides the consideration of energy resilience. Such study is important to further explore the potential use of DR so that the result of the study can be compared to this study which is based on different implementation approach of DR.
- Assessment of system performance during unresilient state. Such study is important as a new perspective of resilience that focuses on the system performance to recover back to resilient state. Time of recovery should play an important factor.
- DR capacity, power demand and other significant factors of a power operation can be considered in a dynamic mode which is a closer representation of reality.

Appendix

Appendix 1 Research philosophy (Sinclair, 2009)

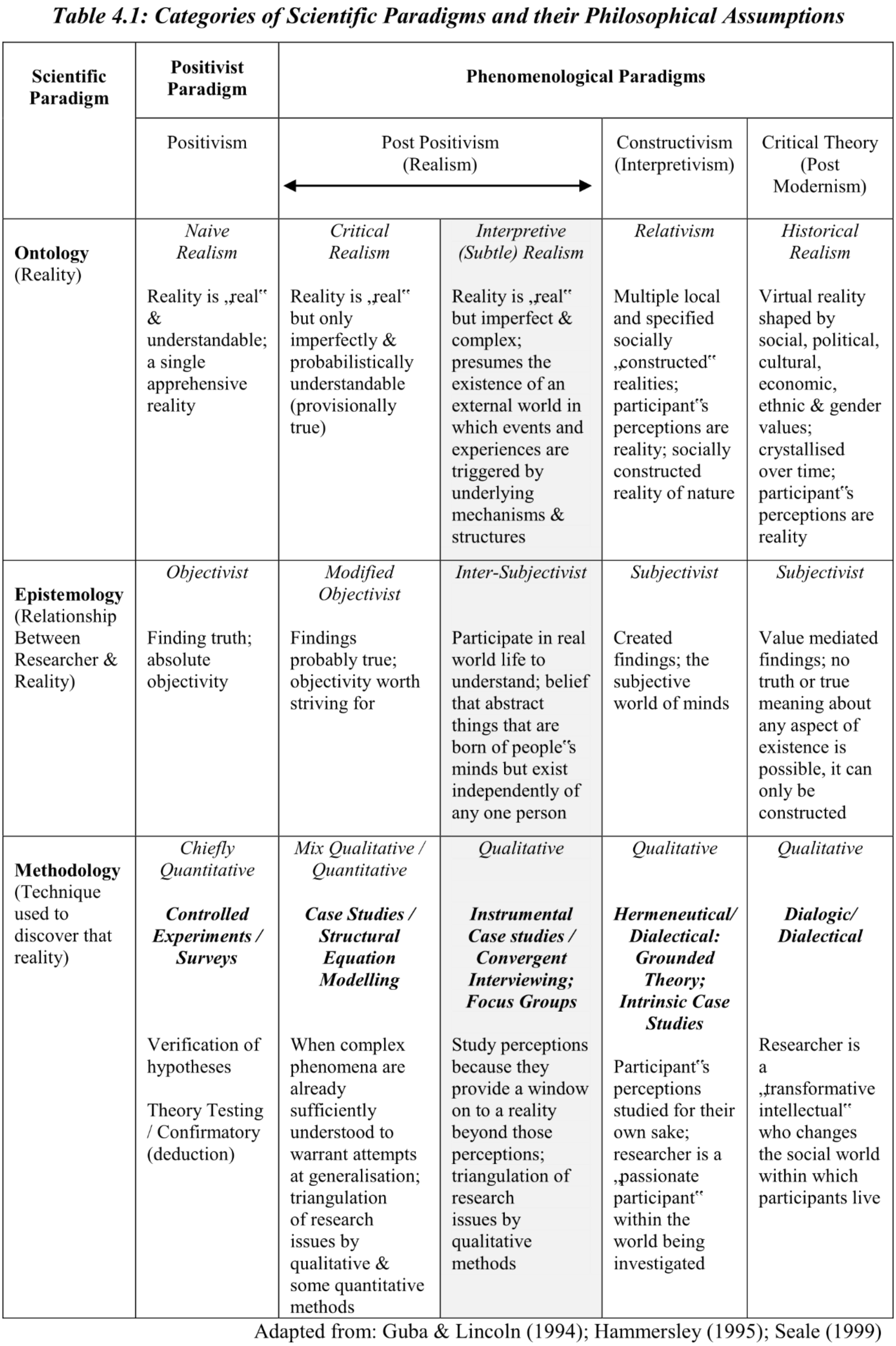


Table 4.1: Categories of Scientific Paradigms and their Philosophical Assumptions

Scientific Paradigm	**Positivist Paradigm**	**Phenomenological Paradigms**			
	Positivism	Post Positivism (Realism) ←→		Constructivism (Interpretivism)	Critical Theory (Post Modernism)
Ontology (Reality)	*Naive Realism* Reality is „real‟ & understandable; a single apprehensive reality	*Critical Realism* Reality is „real‟ but only imperfectly & probabilistically understandable (provisionally true)	*Interpretive (Subtle) Realism* Reality is „real‟ but imperfect & complex; presumes the existence of an external world in which events and experiences are triggered by underlying mechanisms & structures	*Relativism* Multiple local and specified socially „constructed‟ realities; participant‟s perceptions are reality; socially constructed reality of nature	*Historical Realism* Virtual reality shaped by social, political, cultural, economic, ethnic & gender values; crystallised over time; participant‟s perceptions are reality
Epistemology (Relationship Between Researcher & Reality)	*Objectivist* Finding truth; absolute objectivity	*Modified Objectivist* Findings probably true; objectivity worth striving for	*Inter-Subjectivist* Participate in real world life to understand; belief that abstract things that are born of people‟s minds but exist independently of any one person	*Subjectivist* Created findings; the subjective world of minds	*Subjectivist* Value mediated findings; no truth or true meaning about any aspect of existence is possible, it can only be constructed
Methodology (Technique used to discover that reality)	*Chiefly Quantitative* ***Controlled Experiments / Surveys*** Verification of hypotheses Theory Testing / Confirmatory (deduction)	*Mix Qualitative / Quantitative* ***Case Studies / Structural Equation Modelling*** When complex phenomena are already sufficiently understood to warrant attempts at generalisation; triangulation of research issues by qualitative & some quantitative methods	*Qualitative* ***Instrumental Case studies / Convergent Interviewing; Focus Groups*** Study perceptions because they provide a window on to a reality beyond those perceptions; triangulation of research issues by qualitative methods	*Qualitative* ***Hermeneutical/ Dialectical: Grounded Theory; Intrinsic Case Studies*** Participant‟s perceptions studied for their own sake; researcher is a „passionate participant‟ within the world being investigated	*Qualitative* ***Dialogic/ Dialectical*** Researcher is a „transformative intellectual‟ who changes the social world within which participants live

Adapted from: Guba & Lincoln (1994); Hammersley (1995); Seale (1999)

Appendix 2 Definitions of various demand response program

2010 FERC Survey Program Classifications	Description
Direct Load Control	Sponsor remotely shuts down or cycles equipment
Interruptible Load	Load subject to curtailment under tariff or contract
Emergency Demand Response	Load reductions during an emergency event Combines direct load control with specified high price
Load as Capacity Resource	Pre-specified load reductions during system contingency
Spinning Reserves	Load reductions synchronized and responsive within the first few minutes of an emergency event
Critical Peak Pricing w/Control	Combines direct load control with specified high price
Non-Spinning Reserves	Demand side resources available within 10 minutes
Regulation Service	Increase or decrease load in response to real-time signal
Demand Bidding and Buyback	Customer offers load reductions at a price
Time-of-Use Pricing	Average unit prices that vary by time period.
Critical Peak Pricing	Rate/price to encourage reduced usage during high wholesale prices or system contingencies
Real-Time Pricing	Retail price fluctuates hourly or more often to reflect changes in wholesale prices on day or hour ahead
Peak Time Rebate	Rebates paid on critical peak hours for reductions against a baseline
System Peak Response Transmission Tariff	Rates / prices to reduce peaks and transmission charges

Appendix 3 Attributes of resilience from literature

Resilience attribute	Literature references
Ability to anticipate	(Afgan, 2010)(Lovins, et al., 1947) (Jackson, 2010)
Ability to perceive	(Afgan, 2010)(Lovins, et al., 1947)
Ability to respond	(Afgan, 2010) (Woods, 2006)
Adaptability	(Biggs, et al., 2011) (Jackson, 2010)(Bajek, et al., 2007)(Windle, 1999)(Hoffman, et al., 2008) (Woods, 2006) (Gao, 2010) (Smit, et al., 2006)(Fiksel, 2006)
Reliability	(Gao, 2010) (Jackson, 2010)
Flexibility	(Woltjer, 2008) (Lovins, et al., 1947)(Dekker, et al., 2008) (Jackson, 2010)
Robustness	(Gao, 2010)(Dekker, et al., 2008)(MCEER)(Fiksel, 2006)
Redundancy	(Gao, 2010)(Lovins, et al., 1947) (Marshall, et al., 2002)(MCEER)
Margin	(Woltjer, 2008)
Buffering capacity	(Woltjer, 2008)
Safety	(Hollnagel, 2010) (Woods, 2006)(Gao, 2010) (Jackson, 2010)
Emergence	(Dekker, et al., 2008)
Cohesion	(Fiksel, 2003)
Tolerance	(Lovins, et al., 1947) (Woltjer, 2008) (Jackson, 2010)
Stability	(Lovins, et al., 1947)
Inter-element collaboration	(Jackson, 2010)(Lovins, et al., 1947)
Diversity	(Lovins, et al., 1947)(MCEER)
Standardization	(Lovins, et al., 1947)

Resilience attribute	Literature references
Dispersion	(Lovins, et al., 1947)
Hierarchical embedding	(Lovins, et al., 1947)
Simplicity	(Lovins, et al., 1947)
Accessibility	(Lovins, et al., 1947)
Reproducibility	(Lovins, et al., 1947)
Capacity	(Cardona, 2003)(Resilience Alliance)(Walker et al. 2004)(Folke, 2006)(Kendra, et al., 2003)(Comfort, 1999)(Sebescen, 2000)(Wildavsky, 1991)(Jackson, 2010)
Proactive	(Woods, 2006)
Recovery	(MCEER)
Repairing	(Gao, 2010)
Availability	(Bonnefoi, 1990)
Culture	(Jackson, 2010)
Management	(Jackson, 2010)
Governance	(Jackson, 2010)

Appendix 4 Explanation of symbols used in table in Appendix 5

Symbol explanation	
A: Inter-element collaboration	K: Safety
B: Decision making	L: Expertise
C: Cultural factors	M: Defect detection & correction
D: Risk management	N: Maintenance
E: Verification	O: Reliability
F: Regulatory process	P: Governance
G: Management oversight	Q: Anticipation
H: Capacity	X: deficienct in the relevant resilience aspect
I: Flexibility	O: sufficient in the relevant resilience aspect
J: Tolerance	Δ: mixed in the relevant resilience aspect

Appendix 5 Analysis of top resilience attributes from case study from a book (Jackson, 2010)

Case name	**Disruption type**	**Resilience aspect**																
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
US Airways 1549	A-external	X	X						X	X	X							
Concorde Aircraft	A-external	X							X	X	X							
Tacoma Narrows Bridge	A-input	X	X						X		O		X					O
NY Power Restoration	A-input	Δ	O						O	O	O							
Katrina Civil Infra System	A-input and B-systemic	X	X						X	X	X							
Challenger	B-systemic	X	X	X	X	X	X	X	X	X	X							
TC 1947	?	X	X				X		X	X	X							
TC 2005	B-systemic	X		X				X	X	X	X							
Piper Alpha	B-systemic	X	X	X			X		X	X	X	X						
Columbia	B-systemic	X		X	X	X		X	X	X	X		X	X				
Chernobyl	B-systemic	X	X		X				X	X	X							
Bhopal	B-systemic	X	X		X			X	X	X	X		X		X			
Three Mile Island	B-systemic	X	Δ	X					O	O	O				X			
Clapham Junction	B-systemic	X	X					X		X	X		X					
TWA 800	B-systemic	X			X				X	X	X	X						
Apollo 13	B-systemic	Δ	O	X	X				O	O	O	X				X		
Flixborough	B-systemic	X	X	X					X	X	X		X		X			
American Flight 191	B-systemic	X							X	X	X				X			
Japan Airlines JL123	B-systemic	X							X	X	X			X	X			
Philips 66	B-systemic	X							X	X	X				X		X	
Seveso	B-systemic	X		X	X			X	X	X	X	X						
Windscale	B-systemic	X		X	X				X	X	X		X					
King's Cross Underground	B-systemic	X		X	X		X	X	X	X	X							
Mars Polar Lander	B-systemic	X							X	X	X							X
Nagoya	B-systemic	X							X	X	X							X
Sioux City	B-systemic	Δ							O	O	O				X			
Valujet	B-systemic	X		X					X	X	X	X						
Mars Climate Orbiter	B-systemic	X							X	X	X		X					
Comet	B-systemic	X							X	X	X		X					
Jesica Santillan	B-systemic	X							O	X	X							X
Helios 522	B-systemic	X							O	X	X							
Metrolink 111	B-systemic	X							X	X	X							
	X	29	10	11	9	2	4	7	25	27	27	5	8	2	7	1	1	3
	Δ	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	O	0	2	0	0	0	0	0	6	4	5	0	0	0	0	0	0	1

Appendix 6 Analysis of resilience definitions

Literature reference	Whose is it? (Subject)	What is it?	What does it do?
(Afgan, 2010)	ecosystem.	a measure	a measure of resistance to the disturbance and the speed to return to the equilibrium state of an ecosystem.
(Afgan, 2010)	system	a measure	a measure of the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior.
(Cardona, 2003)	damaged ecosystem or community	capacity	absorb negative impacts and recover from these.
(Chambers Dictionary definition)	entity or system	ability	recover form and position elastically' following a disturbance or disruption of some kind
(Comfort, 1999)		capacity	adapt existing resources and skills to new systems and operating conditions.
(Dekker, et al., 2008)		ability	accommodate change, conflict, disturbance, without breaking down, without catastrophic failure
(Folke, 2006)	system	capacity	absorb disturbance; self-organise; and incorporate learning and adaptation in order to maintain core functions.
(Hoffman, et al., 2008)	system	ability	absorb a significant negative change and return to an acceptable state
(Hoffman, et al., 2008)		ability	recognize and adapt to handle unanticipated perturbations that call into question the model of competence, and demand a shift of processes, strategies and coordination
(Hoffman, et al., 2008)	organisation	intrinsic ability	maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap and/or in the presence of a continuous stress.
(Hollnagel, 2010)	system or organisation	intrinsic ability	adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions.
(Hollnagel, et al., 2006)		3 abilities	the ability to prevent something bad from happening the ability to prevent something bad from becoming worse the ability to recover from something bad once it has happened
(Hollnagel, et al., 2006)	system	ability	effectively adjust to hazardous influences, rather than resist or deflect them.
(Horne, et al., 1998)	individuals, groups and organizations , and systems as a whole	fundamental quality	respond productively to significantly change that disrupts the expected pattern of events without engaging in an extended period of regressive behavior.
(Kahn, 1978)	system	ability	to absorb such shocks gracefully
(Kendra, et al., 2003)		capacity	cope with unanticipated dangers
(Kendra, et al., 2004)	individual or organization	ability	implement positive adaptive behaviors that match the situation at hand while at the same time minimizing the associated stress.
(Kendra, et al., 2005)		ability	respond to significant change that disrupts the expected pattern of events without engaging in extended periods of regressive behavior.
(Mallak, 1998)	individual or organization	ability	expeditiously design and implement positive adaptive behaviours matched to the immediate situation, while enduring minimal stress.
(Manfred, et al.)			emphasizes conditions far from any equilibrium steady state, where instabilities can shift a system to another

Literature reference	Whose is it? (Subject)	What is it?	What does it do?
			basin of attraction which is controlled by a different set of variables and characterized by a different structure.
(Mileti, 1999)	locale	ability	withstand an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life and without large amounts of assistance from outside the community.
(Pulley, et al., 2001)		ability	recover quickly from change, hardship, or misfortune.
(Resilience Alliance)	ecosystem	capacity	tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes.
(Sebescen, 2000)		capacity	overcome and thrive in the face of adversity
(Walker et al. 2004).	system	capacity	adjust to, and absorb change, in order to maintain essential structures and functions despite disturbances
(Walker, 2004)			concentrates on stability near an equilibrium steady state
(Wildavsky, 1991)		capacity	cope with unanticipated dangers after they have become manifest, learning to bounce back
(Windle, 1999)		successful adaptation	successful adaptation to life tasks in the face of social disadvantage or highly adverse conditions
(Wreathall, 2006)	organisation	ability	keep, or recover quickly to, a stable state, allowing it to continue operations during and after a major mishap or in the presence of continuous significant stresses.
(Chapel, et al., 2010)	system	capacity	restore its properties of interest, lost after disturbances.

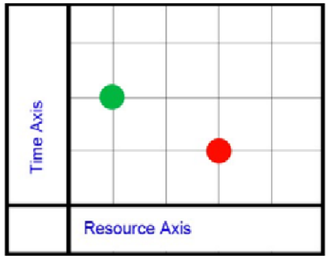
Appendix 7 List of resilience definitions

First Author, Year	Level of Analysis	Definition
Gordon, 1978	Physical	The ability to store strain energy and deflect elastically under a load without breaking or being deformed
Bodin, 2004	Physical	The speed with which a system returns to equilibrium after displacement, irrespective of how many oscillations are required
Holling, 1973	Ecological system	The persistence of relationships within a system; a measure of the ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist
Waller, 2001	Ecological system	Positive adaptation in response to adversity; it is not the absence of vulnerability, not an inherent characteristic, and not static
Klein, 2003	Ecological system	The ability of a system that has undergone stress to recover and return to its original state; more precisely (i) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction and (ii) the degree to which the system is capable of self-organization (see also Carpenter et al. 2001)
Longstaff, 2005	Ecological system	The ability by an individual, group, or organization to continue its existence (or remain more or less stable) in the face of some sort of surprise… Resilience is found in systems that are highly adaptable (not locked into specific strategies) and have diverse resources
Resilience Alliance, 2006	Ecological system	The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks- and therefore the same identity. (Retrieved 10/16/2006 from http://www.resalliance.org/564.php)
Adger, 2000	Social	The ability of communities to withstand external shocks to their social infrastructure
Bruneau, 2003	Social	The ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes
Godschalk, 2003	City	A sustainable network of physical systems and human communities, capable of managing extreme events; during disaster, both must be able to survive and function under extreme stress
Brown, 1996	Community	The ability to recover from or adjust easily to misfortune or sustained life stress
Sonn, 1998	Community	The process through which mediating structures (schools, peer groups, family) and activity settings moderate the impact of oppressive systems
Paton, 2000	Community	The capability to bounce back and to use physical and economic resources effectively to aid recovery following exposure to hazards
Ganor, 2003	Community	The ability of individuals and communities to deal with a state of continuous, long term stress; the ability to find unknown inner strengths and resources in order to cope effectively; the measure of adaptation and flexibility
Ahmed, 2004	Community	The development of material, physical, socio-political, socio-cultural, and psychological resources that promote safety of residents and buffer adversity
Kimhi, 2004	Community	Individuals' sense of the ability of their own community to deal successfully with the ongoing political violence
Coles, 2004	Community	A community’s capacities, skills, and knowledge that allow it to participate fully in recovery from disasters
Pfefferbaum, 2005	Community	The ability of community members to take meaningful, deliberate, collective action to remedy the impact of a problem, including the ability to interpret the environment, intervene, and move on
Masten, 1990	Individual	The process of, capacity for, or outcome of successful adaptation despite challenging or threatening circumstances
Egeland, 1993	Individual	The capacity for successful adaptation, positive functioning, or competence… despite high-risk status, chronic stress, or following prolonged or severe trauma
Butler, 2007	Individual	Good adaptation under extenuating circumstances; a recovery trajectory that returns to baseline functioning following a challenge

First Author, Year	Level of Analysis	Definition
Norris, 2008	Community	A process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance
Renn, 2002	Community	Countermeasure to uncertainties by avoiding irreversibility and vulnerabilities
Rose, 2007	System	the ability of an entity or system to maintain function (e.g. continue producing) when shocked
Cutter, 2008	Community	ability of a social system to respond and recover from disasters
O'Brien, 2010	System	ability to withstand and adjust to disruptions whilst still retaining function
Walker, 2004	System	capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks

Appendix 8 Approaches to measure or assessing resilience (UNESCAP, 2008)

Assessment objective and context	Approach/methodology	Result	Comments re: assessment	Reference
Methodologies requiring a case-study approach				
To measure improvements in the disaster resilience of communities – comparing the resilience of two seismic retrofit projects	Estimation loss modeling	Only one retrofit project improves resilience, but not to an adequate degree	Resilience framework can guide mitigation and preparedness efforts; resilience quantification must move beyond loss-estimate	Chang, S. E. and Shinokuza, M. (2004). "Measuring Improvements in the Disaster Resilience of Communities", in Earthquake Spectra, Vol. 20, Issue 3, pp 739-755
To measure resilience in stochastic ecological systems	Resistance=magnitude of change in pop. density brought about by env. perturbation (PIMM 1984a) Deterministic resilience = return time to equilibrium Stochastic resilience = ratio of variability in pop. Densities to variability in pop. Growth rates [calc. from community matrix describing average interaction strengths within and among species)	Simple methodology that can be applied to a wider range of ecological communities	Although there are communities in which pop. densities are sufficiently constant, and perturbations sufficiently large and infrequent to estimate return times to equilibrium, these communities are probably exceptions to the rule	Ives, A. (1995). "Measuring Resilience in Stochastic Systems", in Ecological Monographs 65 (2) 1995, pp. 217-233. Ecological Society of America
To measure resilience and assess comparative resilience of multiple scenarios.	Resilience = return time to equilibrium Resilience is accessed by dividing the number of times a satisfactory performance value follows an unsatisfactory performance value by the total number of unsatisfactory values.	Simple methodology that can be applied to multiple alternative	Resilience along with reliability and vulnerability help in selecting the most sustainable alternative	Loucks, Daniel and John Gladwell (eds). Sustainability Criteria for Water Resource Systems. Cambridge University Press: 1999
To measure economic (production) losses due to a water supply disruption. - economic system, water scarcity	CGE modeling applied to estimate economic losses	"Indirect (pure general equilibrium) economic losses vary according to the overall level and sectoral mix of water shortages, the extent of pre-event mitigation and post-event inherent and adaptive resilience."	Methodology can be adapted to other applications of CGE models for response to other types of disasters.	Rose, A. (undated). Defining and Measuring Economic Resilience to Earthquakes. Multidisciplinary Center for Earthquake Engineering. Accessed at <http://mceer.buffalo.edu/publications/resaccom/04-sp01/04_rose.pdf>.

Assessment objective and context	Approach/methodology	Result	Comments re: assessment	Reference
To define a single measure of *resiliency*	Differentiates between ***resilience*** (measures the degree of shock needed to cause perturbations), and ***resiliency*** (the time needed to recover from perturbations). Resiliency is measured in two dimensions: (1) time to recovery; (2) the amount of labour, capital, and land invested in recovery. In the diagram below, the different spots indicate two different systems, identification of which has greater resiliency is difficult to identify. A single resiliency score can be determined by plotting the ordinates (A,B) and calculating the area of the rectangle with sides (0,0) to (A,0) and (0,0) to (0,B). 	Proposed, not tested	Proposed , not tested, could be adapted to reflect resilience, rather than resiliency, plotting time taken to recover against the degree of shock	Proposed in a 2006 blog posting at <http://www.tdaxp.com/archive/2006/09/10/be-resilient-part-iii-how-to-measure resiliency.html>
Methodologies for macro-analysis and cross-system comparison				
To define an economic resilience index and use it to explore relationships between resilience and GDP	Resilience index based on a simple average of four components, transformed to a value from 0-1: 1. macro-economic stability (fiscal deficit to GDP ratio, sum of unemployment and inflation rates and the external debt to GDP ratio) 2. micro-economic market efficiency (data from the Economic Freedom of the World Index relating to size of government and freedom to trade internationally) 3. good governance (data from the Economic Freedom of the World Index focusing on legal structure and security of property rights) 4. Social development (data from the HDI relating to education and health).	GDP per capita is positively related to economic resilience and negatively related to inherent economic vulnerability. Per capita GDP is more sensitive to resilience than to vulnerability.	The authors note the utility of possibly including the effects of environmental management on economic resilience but cite reservations due to data availability and the potential for high correlation with environmental management.	L. Briguglio, G. Concordina, S. Bugeja, and Farrugia N. (undated) "Conceptualizing and Measuring Economic Resilience" (accessed at < http://home.um.edu.mt/islands/resilience_index.pdf>. Economics Department, University of Malta.

Assessment objective and context	Approach/methodology	Result	Comments re: assessment	Reference
To define a single measure of the resilience of an economy	Resilience = degree of shock needed to cause a perturbation. Also measures recovery from perturbation. Proposes to identifies a single measure of resilience by: 1. determining what factors cause system-perturbations, in relation to specific factors of production – e.g. land, labour, capital etc 2. Measuring the resilience in each factor (no details provided). 3. Quantifying total resilience by assigning weights (1,3,9 for low, medium, high) to each factor and then a score for the country for each factor (1,3,9 for l, m, h)…multiple…add get a total score. Another approach might be to use a numeric scale based on standard deviation. (no details provided	Based on a record of an exchange of ideas on measuring resilience, not tested	Example given for Singapore, "assessing" resilience in various factors. Resilience is rated high for production factors that can be purchased, for example.:	2006 blog archive accessed at <http://www.tdaxp.com/archive/2006/09/01/be-resilient-part-i-how-to-measure resilience.html>

Appendix 9 Estimation of demand response potential of various building types based on consideration of season, peak status and significance of building function

House	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.7	0.5	0.9	0.7	0.5	0.9	0.7	0.5
Hot water	0.9	0.9	0.8	0.9	0.7	0.7	0.9	0.8	0.8
Heating	0.9	0.9	0.9	0.5	0.7	0.5	0.8	0.8	0.8
Cooling	0.5	0.7	0.6	0.9	0.9	0.9	0.9	0.9	0.9

Apartment	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.7	0.5	0.9	0.7	0.5	0.9	0.7	0.5
Hot water	0.9	0.9	0.8	0.9	0.7	0.7	0.9	0.8	0.8
Heating	0.9	0.9	0.9	0.5	0.7	0.5	0.8	0.8	0.8
Cooling	0.5	0.7	0.6	0.9	0.9	0.9	0.9	0.9	0.9

Office (standard)	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.6	0.9	0.9	0.6	0.9	0.9	0.6	0.9
Hot water	0.9	0.8	0.9	0.9	0.6	0.8	0.9	0.7	0.9
Heating	0.9	0.9	0.9	0.9	0.5	0.8	0.9	0.8	0.9
Cooling	0.9	0.5	0.7	0.9	0.9	0.9	0.9	0.8	0.9

Office (OA type)	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.5	0.9	0.9	0.5	0.9	0.9	0.5	0.9
Hot water	0.9	0.8	0.9	0.9	0.6	0.8	0.9	0.7	0.9
Heating	0.9	0.9	0.9	0.9	0.5	0.8	0.9	0.8	0.9
Cooling	0.9	0.5	0.7	0.9	0.9	0.9	0.9	0.7	0.9

Shop	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.6	0.9	0.6	0.9	0.9	0.9	0.7	0.9
Hot water	0.9	0.8	0.9	0.9	0.5	0.9	0.9	0.6	0.9
Heating	0.9	0.9	0.9	0.9	0.5	0.9	0.9	0.9	0.9
Cooling	0.9	0.5	0.9	0.9	0.9	0.9	0.9	0.8	0.9

Clinic	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.6	0.9	0.9	0.6	0.9	0.9	0.6	0.9
Hot water	0.9	0.7	0.9	0.9	0.5	0.9	0.9	0.6	0.9
Heating	0.9	0.9	0.9	0.9	0.5	0.9	0.9	0.6	0.9
Cooling	0.9	0.5	0.9	0.9	0.9	0.9	0.9	0.7	0.9

Hotel	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Hot water	0.7	0.6	0.6	0.6	0.4	0.3	0.6	0.6	0.5
Heating	0.9	0.9	0.9	0.3	0.4	0.3	0.4	0.5	0.4
Cooling	0.5	0.4	0.3	0.9	0.9	0.9	0.4	0.5	0.4

Sports center	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.6	0.6	0.9	0.6	0.6	0.9	0.6	0.6
Hot water	0.9	0.8	0.8	0.9	0.4	0.4	0.9	0.6	0.6
Heating	0.9	0.9	0.9	0.9	0.4	0.4	0.9	0.6	0.6
Cooling	0.9	0.4	0.4	0.9	0.9	0.9	0.9	0.6	0.6

Factory	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.6	0.9	0.9	0.6	0.9	0.9	0.6	0.9
Hot water	0.9	0.8	0.9	0.9	0.5	0.9	0.9	0.6	0.9
Heating	0.9	0.9	0.9	0.9	0.5	0.9	0.9	0.9	0.9
Cooling	0.9	0.6	0.9	0.9	0.9	0.9	0.9	0.8	0.9

Others	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.9	0.6	0.9	0.6	0.9	0.9	0.9	0.7	0.9
Hot water	0.9	0.8	0.9	0.9	0.5	0.9	0.9	0.6	0.9
Heating	0.9	0.9	0.9	0.9	0.5	0.9	0.9	0.9	0.9
Cooling	0.9	0.5	0.9	0.9	0.9	0.9	0.9	0.8	0.9

School	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.8	0.7	0.7	0.8	0.7	0.7	0.8	0.7	0.7
Hot water	0.9	0.8	0.9	0.9	0.5	0.7	0.9	0.8	0.7
Heating	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.8	0.9
Cooling	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9

Hospital	Rate of ongoing power demand applicable as demand response capacity								
Season	Summer			Winter			Spring/fall		
Peak status	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400	0000-0900	0900-2000	2000-2400
Electric use	0.3	0.1	0.3	0.3	0.1	0.3	0.3	0.1	0.3
Hot water	0.3	0.3	0.3	0.1	0.1	0.1	0.2	0.2	0.2
Heating	0.9	0.9	0.9	0.2	0.2	0.2	0.4	0.4	0.4
Cooling	0.2	0.2	0.2	0.9	0.9	0.9	0.4	0.4	0.4

Appendix 10 Unit demand of different energy use for different building types (adapted from [日本エネルギー学会, 2008])

Load type	Unit	House	Apartment	Office (standard)	Office (OA type)	Shop	Clinic	Hotel	Factory	Others	School	Hospital
Electricity	kW/m2y	21.00	21.00	156.00	189.00	226.00	170.00	200.00	400.00	226.00	14.62	170.00
Hot water	kW/m2y	34.90	25.00	2.60	2.10	26.70	93.00	93.00	26.70	26.70	18.06	93.00
Heating	kW/m2y	23.30	23.30	36.00	68.60	40.70	86.00	93.00	40.70	40.70	20.64	86.00
Cooling	kW/m2y	9.30	8.00	81.40	153.50	145.30	93.00	116.30	145.30	145.30	2.58	93.00
Total	kW/m2y	88.50	77.30	276.00	413.20	438.70	442.00	502.30	612.70	438.70	55.90	442.00

Appendix 11 Collective hourly unit demand per BFA from January to December for house

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0120	0.0119	0.0107	0.0071	0.0039	0.0019	0.0019	0.0019	0.0015	0.0029	0.0061	0.0097
1	0.0061	0.0058	0.0052	0.0029	0.0011	0.0020	0.0020	0.0020	0.0016	0.0010	0.0029	0.0049
2	0.0045	0.0042	0.0038	0.0022	0.0009	0.0016	0.0017	0.0017	0.0014	0.0009	0.0022	0.0035
3	0.0042	0.0039	0.0036	0.0021	0.0008	0.0007	0.0010	0.0013	0.0009	0.0008	0.0021	0.0033
4	0.0043	0.0040	0.0036	0.0021	0.0008	0.0005	0.0007	0.0009	0.0006	0.0008	0.0021	0.0034
5	0.0056	0.0053	0.0048	0.0023	0.0008	0.0006	0.0009	0.0010	0.0007	0.0007	0.0023	0.0044
6	0.0104	0.0102	0.0093	0.0067	0.0041	0.0023	0.0025	0.0027	0.0022	0.0034	0.0059	0.0084
7	0.0180	0.0178	0.0161	0.0091	0.0048	0.0039	0.0047	0.0053	0.0036	0.0039	0.0082	0.0146
8	0.0154	0.0152	0.0137	0.0081	0.0046	0.0044	0.0056	0.0064	0.0042	0.0037	0.0072	0.0125
9	0.0160	0.0160	0.0144	0.0083	0.0047	0.0038	0.0054	0.0064	0.0038	0.0038	0.0073	0.0130
10	0.0119	0.0120	0.0108	0.0063	0.0040	0.0036	0.0053	0.0064	0.0037	0.0033	0.0055	0.0097
11	0.0138	0.0137	0.0123	0.0075	0.0043	0.0041	0.0063	0.0076	0.0042	0.0035	0.0067	0.0112
12	0.0130	0.0127	0.0115	0.0066	0.0036	0.0043	0.0072	0.0091	0.0046	0.0030	0.0060	0.0105
13	0.0130	0.0127	0.0115	0.0066	0.0036	0.0049	0.0092	0.0121	0.0055	0.0030	0.0060	0.0105
14	0.0125	0.0122	0.0111	0.0063	0.0034	0.0050	0.0098	0.0130	0.0057	0.0029	0.0058	0.0101
15	0.0129	0.0126	0.0114	0.0065	0.0034	0.0046	0.0083	0.0107	0.0050	0.0029	0.0060	0.0104
16	0.0154	0.0154	0.0139	0.0089	0.0054	0.0060	0.0087	0.0104	0.0056	0.0043	0.0076	0.0125
17	0.0244	0.0249	0.0224	0.0173	0.0117	0.0085	0.0109	0.0121	0.0071	0.0087	0.0139	0.0201
18	0.0269	0.0276	0.0248	0.0210	0.0147	0.0113	0.0134	0.0144	0.0093	0.0111	0.0169	0.0222
19	0.0319	0.0332	0.0298	0.0251	0.0182	0.0177	0.0251	0.0296	0.0161	0.0140	0.0200	0.0266
20	0.0338	0.0355	0.0318	0.0257	0.0187	0.0178	0.0262	0.0313	0.0164	0.0143	0.0205	0.0283
21	0.0304	0.0317	0.0285	0.0197	0.0137	0.0170	0.0241	0.0283	0.0154	0.0107	0.0162	0.0253
22	0.0265	0.0273	0.0245	0.0194	0.0136	0.0150	0.0182	0.0198	0.0125	0.0105	0.0158	0.0219
23	0.0219	0.0224	0.0201	0.0145	0.0095	0.0099	0.0134	0.0155	0.0090	0.0077	0.0124	0.0181

Appendix 12 Collective hourly unit demand per BFA from January to December for apartment

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0109	0.0107	0.0097	0.0060	0.0030	0.0015	0.0016	0.0019	0.0013	0.0023	0.0054	0.0088
1	0.0060	0.0056	0.0051	0.0028	0.0011	0.0016	0.0017	0.0020	0.0014	0.0010	0.0028	0.0047
2	0.0044	0.0041	0.0038	0.0022	0.0009	0.0013	0.0014	0.0017	0.0012	0.0009	0.0022	0.0035
3	0.0042	0.0039	0.0036	0.0021	0.0008	0.0007	0.0010	0.0013	0.0009	0.0008	0.0021	0.0033
4	0.0043	0.0040	0.0036	0.0021	0.0008	0.0004	0.0007	0.0009	0.0006	0.0008	0.0021	0.0034
5	0.0055	0.0051	0.0047	0.0022	0.0007	0.0006	0.0008	0.0010	0.0006	0.0006	0.0023	0.0043
6	0.0096	0.0094	0.0085	0.0059	0.0035	0.0020	0.0023	0.0027	0.0020	0.0029	0.0053	0.0077
7	0.0166	0.0162	0.0147	0.0081	0.0040	0.0033	0.0042	0.0053	0.0033	0.0033	0.0075	0.0134
8	0.0142	0.0139	0.0126	0.0072	0.0038	0.0037	0.0049	0.0064	0.0037	0.0032	0.0066	0.0115
9	0.0147	0.0144	0.0130	0.0074	0.0039	0.0033	0.0047	0.0064	0.0034	0.0033	0.0067	0.0119
10	0.0108	0.0107	0.0097	0.0056	0.0034	0.0031	0.0047	0.0064	0.0034	0.0029	0.0050	0.0088
11	0.0128	0.0125	0.0113	0.0067	0.0036	0.0036	0.0055	0.0076	0.0038	0.0031	0.0061	0.0103
12	0.0121	0.0118	0.0107	0.0060	0.0031	0.0037	0.0063	0.0091	0.0041	0.0027	0.0056	0.0098
13	0.0121	0.0118	0.0107	0.0060	0.0031	0.0043	0.0081	0.0121	0.0049	0.0027	0.0056	0.0098
14	0.0119	0.0114	0.0104	0.0059	0.0030	0.0044	0.0086	0.0130	0.0051	0.0026	0.0055	0.0095
15	0.0122	0.0118	0.0107	0.0060	0.0030	0.0040	0.0073	0.0107	0.0045	0.0026	0.0057	0.0098
16	0.0140	0.0138	0.0125	0.0077	0.0044	0.0050	0.0074	0.0104	0.0049	0.0036	0.0068	0.0113
17	0.0216	0.0217	0.0195	0.0141	0.0090	0.0068	0.0091	0.0121	0.0060	0.0068	0.0117	0.0176
18	0.0236	0.0238	0.0214	0.0172	0.0115	0.0090	0.0111	0.0144	0.0078	0.0089	0.0142	0.0193
19	0.0273	0.0280	0.0252	0.0206	0.0144	0.0144	0.0213	0.0296	0.0138	0.0113	0.0169	0.0226
20	0.0287	0.0296	0.0266	0.0211	0.0148	0.0146	0.0222	0.0313	0.0141	0.0115	0.0172	0.0238
21	0.0261	0.0267	0.0240	0.0165	0.0110	0.0139	0.0204	0.0283	0.0132	0.0088	0.0140	0.0215
22	0.0230	0.0233	0.0210	0.0162	0.0108	0.0120	0.0152	0.0198	0.0107	0.0086	0.0136	0.0189
23	0.0194	0.0195	0.0175	0.0126	0.0079	0.0082	0.0115	0.0155	0.0079	0.0065	0.0111	0.0158

Appendix 13 Collective hourly unit demand per BFA from January to December for office (standard)

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0034	0.0035	0.0034	0.0034	0.0033	0.0036	0.0038	0.0042	0.0038	0.0036	0.0036	0.0033
1	0.0030	0.0031	0.0031	0.0031	0.0031	0.0032	0.0034	0.0037	0.0034	0.0033	0.0033	0.0030
2	0.0028	0.0028	0.0028	0.0028	0.0028	0.0030	0.0032	0.0035	0.0032	0.0030	0.0030	0.0027
3	0.0028	0.0028	0.0028	0.0030	0.0030	0.0030	0.0032	0.0035	0.0032	0.0032	0.0032	0.0027
4	0.0027	0.0028	0.0027	0.0028	0.0028	0.0030	0.0032	0.0035	0.0032	0.0030	0.0030	0.0027
5	0.0028	0.0028	0.0028	0.0033	0.0032	0.0030	0.0032	0.0035	0.0032	0.0034	0.0035	0.0027
6	0.0039	0.0041	0.0040	0.0038	0.0037	0.0041	0.0044	0.0046	0.0042	0.0040	0.0040	0.0039
7	0.0078	0.0079	0.0077	0.0074	0.0075	0.0113	0.0181	0.0312	0.0194	0.0083	0.0078	0.0075
8	0.0770	0.0699	0.0626	0.0269	0.0297	0.0403	0.0753	0.1438	0.0831	0.0374	0.0389	0.0622
9	0.0693	0.0647	0.0592	0.0338	0.0378	0.0470	0.0812	0.1476	0.0885	0.0470	0.0454	0.0585
10	0.0565	0.0538	0.0501	0.0337	0.0381	0.0486	0.0821	0.1472	0.0891	0.0462	0.0409	0.0493
11	0.0646	0.0610	0.0562	0.0343	0.0389	0.0493	0.0839	0.1510	0.0911	0.0474	0.0422	0.0555
12	0.0647	0.0610	0.0562	0.0363	0.0384	0.0498	0.0847	0.1525	0.0920	0.0462	0.0469	0.0555
13	0.0656	0.0621	0.0573	0.0356	0.0387	0.0497	0.0843	0.1515	0.0916	0.0471	0.0470	0.0565
14	0.0581	0.0553	0.0514	0.0360	0.0392	0.0491	0.0827	0.1479	0.0898	0.0477	0.0472	0.0506
15	0.0570	0.0542	0.0504	0.0356	0.0385	0.0513	0.0910	0.1681	0.0996	0.0467	0.0466	0.0496
16	0.0598	0.0566	0.0525	0.0326	0.0335	0.0484	0.0820	0.1471	0.0891	0.0380	0.0370	0.0517
17	0.0446	0.0429	0.0403	0.0271	0.0274	0.0441	0.0785	0.1453	0.0859	0.0303	0.0298	0.0395
18	0.0220	0.0228	0.0225	0.0212	0.0211	0.0307	0.0459	0.0749	0.0487	0.0230	0.0225	0.0218
19	0.0191	0.0198	0.0196	0.0184	0.0181	0.0220	0.0248	0.0293	0.0247	0.0196	0.0196	0.0190
20	0.0153	0.0158	0.0156	0.0143	0.0142	0.0161	0.0186	0.0226	0.0186	0.0155	0.0152	0.0151
21	0.0119	0.0123	0.0122	0.0106	0.0105	0.0116	0.0124	0.0134	0.0122	0.0113	0.0114	0.0118
22	0.0083	0.0085	0.0084	0.0076	0.0075	0.0083	0.0088	0.0095	0.0087	0.0081	0.0081	0.0082
23	0.0040	0.0042	0.0041	0.0041	0.0040	0.0044	0.0046	0.0050	0.0046	0.0043	0.0043	0.0040

Appendix 14 Collective hourly unit demand per BFA from January to December for office (OA type)

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0090	0.0091	0.0092	0.0095	0.0094	0.0103	0.0106	0.0104	0.0101	0.0095	0.0094	0.0088
1	0.0081	0.0082	0.0083	0.0085	0.0085	0.0084	0.0087	0.0085	0.0082	0.0086	0.0084	0.0080
2	0.0081	0.0082	0.0083	0.0085	0.0085	0.0084	0.0087	0.0085	0.0082	0.0086	0.0084	0.0080
3	0.0081	0.0082	0.0083	0.0085	0.0085	0.0084	0.0087	0.0085	0.0082	0.0086	0.0084	0.0080
4	0.0081	0.0082	0.0083	0.0085	0.0085	0.0084	0.0087	0.0085	0.0082	0.0086	0.0084	0.0080
5	0.0081	0.0082	0.0083	0.0089	0.0087	0.0084	0.0087	0.0085	0.0082	0.0088	0.0087	0.0080
6	0.0083	0.0085	0.0085	0.0086	0.0085	0.0085	0.0088	0.0086	0.0083	0.0086	0.0084	0.0081
7	0.0090	0.0091	0.0086	0.0086	0.0086	0.0167	0.0186	0.0196	0.0170	0.0088	0.0084	0.0086
8	0.1435	0.1421	0.1162	0.0779	0.0715	0.0822	0.0950	0.1029	0.0854	0.0753	0.0902	0.1410
9	0.1204	0.1200	0.1018	0.0830	0.0782	0.0834	0.0959	0.1035	0.0864	0.0824	0.0943	0.1200
10	0.0989	0.0991	0.0880	0.0767	0.0769	0.0857	0.0981	0.1055	0.0885	0.0808	0.0826	0.0886
11	0.1123	0.1125	0.0974	0.0786	0.0782	0.0907	0.1035	0.1111	0.0935	0.0822	0.0853	0.1017
12	0.1133	0.1133	0.0980	0.0808	0.0756	0.0895	0.1020	0.1094	0.0922	0.0794	0.0907	0.1117
13	0.1135	0.1141	0.0986	0.0824	0.0776	0.0906	0.1035	0.1110	0.0935	0.0815	0.0932	0.1131
14	0.1009	0.1012	0.0895	0.0825	0.0779	0.0910	0.1039	0.1115	0.0939	0.0818	0.0931	0.1024
15	0.0993	0.0995	0.0883	0.0812	0.0766	0.0962	0.1103	0.1188	0.0994	0.0804	0.0915	0.1005
16	0.1045	0.1045	0.0918	0.0604	0.0617	0.0893	0.1018	0.1092	0.0920	0.0644	0.0629	0.0841
17	0.0844	0.0849	0.0781	0.0548	0.0573	0.0904	0.1033	0.1108	0.0933	0.0596	0.0556	0.0629
18	0.0522	0.0537	0.0562	0.0515	0.0549	0.0677	0.0757	0.0798	0.0690	0.0570	0.0511	0.0333
19	0.0170	0.0174	0.0174	0.0178	0.0175	0.0196	0.0206	0.0205	0.0193	0.0178	0.0175	0.0167
20	0.0150	0.0152	0.0153	0.0164	0.0163	0.0195	0.0205	0.0204	0.0192	0.0166	0.0161	0.0147
21	0.0131	0.0133	0.0134	0.0139	0.0137	0.0141	0.0146	0.0143	0.0138	0.0140	0.0137	0.0129
22	0.0107	0.0108	0.0109	0.0113	0.0112	0.0131	0.0136	0.0133	0.0129	0.0114	0.0111	0.0105
23	0.0098	0.0099	0.0100	0.0104	0.0102	0.0112	0.0116	0.0114	0.0110	0.0104	0.0102	0.0096

Appendix 15 Collective hourly unit demand per BFA from January to December for shop

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
1	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
2	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
3	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
4	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
5	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
6	0.0021	0.0023	0.0022	0.0021	0.0023	0.0021	0.0021	0.0019	0.0021	0.0022	0.0020	0.0023
7	0.0072	0.0080	0.0078	0.0071	0.0078	0.0070	0.0069	0.0065	0.0071	0.0076	0.0068	0.0081
8	0.1016	0.1096	0.0769	0.0516	0.0723	0.0940	0.1161	0.1195	0.0989	0.0789	0.0482	0.0878
9	0.1073	0.1177	0.0934	0.0753	0.0954	0.1145	0.1347	0.1365	0.1199	0.1007	0.0710	0.1028
10	0.0971	0.1083	0.0902	0.0774	0.0996	0.1198	0.1430	0.1456	0.1258	0.1058	0.0730	0.0975
11	0.0882	0.0989	0.0829	0.0720	0.0961	0.1173	0.1414	0.1444	0.1229	0.1029	0.0675	0.0885
12	0.0839	0.0960	0.0853	0.0793	0.1055	0.1291	0.1572	0.1611	0.1358	0.1134	0.0746	0.0896
13	0.0876	0.1008	0.0918	0.0877	0.1132	0.1374	0.1664	0.1702	0.1449	0.1211	0.0828	0.0964
14	0.0825	0.0964	0.0909	0.0905	0.1184	0.1449	0.1768	0.1813	0.1530	0.1272	0.0855	0.0942
15	0.0739	0.0865	0.0812	0.0810	0.1105	0.1373	0.1686	0.1733	0.1444	0.1195	0.0759	0.0832
16	0.0805	0.0919	0.0812	0.0759	0.1020	0.1257	0.1523	0.1559	0.1319	0.1095	0.0712	0.0850
17	0.0904	0.1014	0.0865	0.0768	0.0983	0.1182	0.1406	0.1430	0.1241	0.1043	0.0725	0.0927
18	0.0916	0.1025	0.0867	0.0743	0.0941	0.1107	0.1321	0.1346	0.1165	0.0997	0.0703	0.0936
19	0.0137	0.0152	0.0149	0.0138	0.0148	0.0134	0.0132	0.0125	0.0137	0.0145	0.0131	0.0155
20	0.0016	0.0017	0.0017	0.0015	0.0016	0.0014	0.0014	0.0013	0.0014	0.0016	0.0014	0.0017
21	0.0010	0.0011	0.0011	0.0009	0.0010	0.0007	0.0007	0.0006	0.0007	0.0010	0.0008	0.0012
22	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
23	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006

Appendix 16 Collective hourly unit demand per BFA from January to December for clinic

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0121	0.0124	0.0119	0.0103	0.0120	0.0145	0.0215	0.0348	0.0227	0.0142	0.0107	0.0117
1	0.0122	0.0123	0.0118	0.0097	0.0113	0.0137	0.0207	0.0341	0.0220	0.0135	0.0101	0.0115
2	0.0116	0.0117	0.0112	0.0091	0.0107	0.0131	0.0197	0.0323	0.0209	0.0128	0.0095	0.0110
3	0.0114	0.0115	0.0110	0.0091	0.0107	0.0129	0.0195	0.0321	0.0207	0.0128	0.0095	0.0108
4	0.0118	0.0119	0.0114	0.0097	0.0111	0.0140	0.0204	0.0329	0.0215	0.0131	0.0099	0.0111
5	0.0520	0.0473	0.0417	0.0185	0.0146	0.0197	0.0336	0.0608	0.0363	0.0172	0.0307	0.0417
6	0.0524	0.0481	0.0430	0.0257	0.0198	0.0246	0.0353	0.0561	0.0368	0.0221	0.0393	0.0428
7	0.0557	0.0513	0.0463	0.0344	0.0284	0.0336	0.0452	0.0677	0.0464	0.0312	0.0464	0.0459
8	0.1239	0.1167	0.1040	0.0537	0.0442	0.0551	0.0803	0.1299	0.0836	0.0481	0.0696	0.1039
9	0.1165	0.1125	0.1012	0.0599	0.0522	0.0623	0.0866	0.1346	0.0890	0.0566	0.0694	0.1010
10	0.1129	0.1101	0.0994	0.0620	0.0544	0.0653	0.0906	0.1407	0.0931	0.0590	0.0705	0.0991
11	0.1027	0.0996	0.0900	0.0548	0.0495	0.0606	0.0873	0.1400	0.0907	0.0546	0.0630	0.0897
12	0.1002	0.0980	0.0887	0.0564	0.0514	0.0618	0.0887	0.1417	0.0919	0.0566	0.0628	0.0884
13	0.0930	0.0925	0.0842	0.0588	0.0533	0.0625	0.0859	0.1323	0.0881	0.0584	0.0645	0.0838
14	0.0895	0.0888	0.0810	0.0567	0.0520	0.0605	0.0843	0.1312	0.0868	0.0571	0.0622	0.0806
15	0.0826	0.0812	0.0741	0.0491	0.0463	0.0552	0.0804	0.1298	0.0838	0.0517	0.0550	0.0737
16	0.0791	0.0771	0.0703	0.0439	0.0419	0.0513	0.0767	0.1266	0.0806	0.0472	0.0498	0.0698
17	0.0780	0.0759	0.0690	0.0426	0.0405	0.0501	0.0749	0.1235	0.0785	0.0456	0.0480	0.0686
18	0.0742	0.0717	0.0650	0.0397	0.0376	0.0468	0.0700	0.1156	0.0735	0.0421	0.0447	0.0647
19	0.0585	0.0571	0.0522	0.0350	0.0323	0.0381	0.0512	0.0766	0.0525	0.0356	0.0400	0.0518
20	0.0505	0.0482	0.0439	0.0273	0.0254	0.0305	0.0436	0.0689	0.0456	0.0286	0.0335	0.0436
21	0.0446	0.0416	0.0375	0.0190	0.0177	0.0228	0.0354	0.0600	0.0377	0.0205	0.0255	0.0372
22	0.0442	0.0406	0.0362	0.0173	0.0149	0.0193	0.0311	0.0540	0.0334	0.0175	0.0266	0.0361
23	0.0140	0.0146	0.0140	0.0122	0.0136	0.0162	0.0231	0.0365	0.0243	0.0159	0.0123	0.0137

Appendix 17 Collective hourly unit demand per BFA from January to December for hotel

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0390	0.0385	0.0317	0.0400	0.0252	0.0335	0.0412	0.0450	0.0373	0.0221	0.0431	0.0381
1	0.0388	0.0379	0.0309	0.0281	0.0199	0.0270	0.0332	0.0365	0.0304	0.0187	0.0309	0.0379
2	0.0366	0.0355	0.0284	0.0233	0.0169	0.0239	0.0299	0.0333	0.0272	0.0161	0.0258	0.0355
3	0.0337	0.0326	0.0263	0.0214	0.0158	0.0224	0.0279	0.0311	0.0256	0.0152	0.0238	0.0328
4	0.0316	0.0307	0.0249	0.0229	0.0173	0.0225	0.0278	0.0307	0.0256	0.0168	0.0255	0.0308
5	0.0370	0.0366	0.0299	0.0288	0.0219	0.0265	0.0315	0.0339	0.0296	0.0211	0.0315	0.0360
6	0.0490	0.0490	0.0407	0.0400	0.0311	0.0375	0.0439	0.0465	0.0413	0.0302	0.0435	0.0478
7	0.0569	0.0565	0.0467	0.0468	0.0352	0.0407	0.0478	0.0509	0.0450	0.0338	0.0511	0.0554
8	0.0656	0.0648	0.0526	0.0477	0.0372	0.0457	0.0550	0.0594	0.0508	0.0357	0.0520	0.0636
9	0.0648	0.0640	0.0569	0.0528	0.0503	0.0540	0.0660	0.0720	0.0603	0.0464	0.0549	0.0634
10	0.0707	0.0699	0.0621	0.0598	0.0537	0.0582	0.0706	0.0767	0.0649	0.0493	0.0625	0.0693
11	0.0692	0.0680	0.0629	0.0635	0.0633	0.0561	0.0687	0.0752	0.0631	0.0556	0.0637	0.0683
12	0.0710	0.0699	0.0666	0.0677	0.0650	0.0774	0.0992	0.1102	0.0858	0.0566	0.0680	0.0700
13	0.0738	0.0728	0.0681	0.0725	0.0692	0.0784	0.1004	0.1113	0.0867	0.0596	0.0723	0.0726
14	0.0717	0.0707	0.0661	0.0700	0.0618	0.0846	0.1102	0.1229	0.0932	0.0539	0.0716	0.0707
15	0.0783	0.0770	0.0685	0.0670	0.0589	0.0734	0.0934	0.1033	0.0813	0.0526	0.0694	0.0767
16	0.0884	0.0869	0.0767	0.0701	0.0606	0.0741	0.0943	0.1042	0.0819	0.0535	0.0723	0.0864
17	0.0880	0.0867	0.0764	0.0741	0.0631	0.0760	0.0964	0.1064	0.0839	0.0557	0.0765	0.0861
18	0.0834	0.0826	0.0733	0.0733	0.0632	0.0789	0.0999	0.1099	0.0868	0.0564	0.0759	0.0817
19	0.0840	0.0840	0.0754	0.0755	0.0689	0.0830	0.1040	0.1133	0.0905	0.0621	0.0773	0.0822
20	0.0618	0.0631	0.0611	0.0570	0.0648	0.0821	0.1023	0.1107	0.0889	0.0622	0.0580	0.0616
21	0.0579	0.0595	0.0588	0.0575	0.0682	0.0686	0.0825	0.0877	0.0742	0.0637	0.0565	0.0576
22	0.0458	0.0474	0.0496	0.0646	0.0679	0.0542	0.0626	0.0655	0.0593	0.0610	0.0639	0.0461
23	0.0454	0.0457	0.0382	0.0481	0.0323	0.0402	0.0475	0.0504	0.0440	0.0296	0.0519	0.0443

Appendix 18 Collective hourly unit demand per BFA from January to December for sports centre

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0038	0.0040	0.0038	0.0039	0.0042	0.0040	0.0046	0.0047	0.0045	0.0041	0.0039	0.0039
1	0.0038	0.0040	0.0038	0.0039	0.0042	0.0040	0.0046	0.0047	0.0045	0.0041	0.0039	0.0039
2	0.0038	0.0040	0.0038	0.0039	0.0042	0.0040	0.0046	0.0047	0.0045	0.0041	0.0039	0.0039
3	0.0038	0.0040	0.0038	0.0039	0.0042	0.0040	0.0046	0.0047	0.0045	0.0041	0.0039	0.0039
4	0.0038	0.0040	0.0038	0.0039	0.0042	0.0040	0.0046	0.0047	0.0045	0.0041	0.0039	0.0039
5	0.0038	0.0040	0.0038	0.0039	0.0042	0.0040	0.0046	0.0047	0.0045	0.0041	0.0039	0.0039
6	0.0274	0.0313	0.0276	0.0886	0.0705	0.1045	0.1074	0.0800	0.0805	0.0658	0.0687	0.0262
7	0.2531	0.3101	0.2618	0.2730	0.2193	0.2302	0.2452	0.2003	0.1902	0.2066	0.2088	0.2119
8	0.3228	0.3964	0.3347	0.3004	0.2380	0.2185	0.2340	0.1933	0.1826	0.2241	0.2281	0.2671
9	0.3129	0.3841	0.3243	0.2802	0.2234	0.1992	0.2147	0.1804	0.1691	0.2108	0.2134	0.2588
10	0.3041	0.3731	0.3151	0.2596	0.2089	0.1793	0.1949	0.1667	0.1552	0.1974	0.1987	0.2518
11	0.2332	0.2850	0.2411	0.1854	0.1577	0.1335	0.1498	0.1374	0.1245	0.1504	0.1463	0.1957
12	0.2087	0.2542	0.2156	0.1549	0.1367	0.1107	0.1275	0.1234	0.1096	0.1314	0.1248	0.1763
13	0.2379	0.2903	0.2460	0.1957	0.1654	0.1422	0.1590	0.1450	0.1317	0.1580	0.1539	0.1996
14	0.2458	0.3000	0.2542	0.2063	0.1731	0.1508	0.1678	0.1512	0.1380	0.1652	0.1617	0.2059
15	0.2633	0.3218	0.2726	0.2305	0.1898	0.1690	0.1858	0.1633	0.1504	0.1806	0.1787	0.2197
16	0.3191	0.3912	0.3308	0.3058	0.2424	0.2266	0.2428	0.2012	0.1896	0.2289	0.2322	0.2640
17	0.3007	0.3680	0.3115	0.2817	0.2259	0.2087	0.2254	0.1902	0.1780	0.2139	0.2153	0.2495
18	0.3146	0.3851	0.3259	0.2987	0.2382	0.2216	0.2381	0.1985	0.1870	0.2250	0.2278	0.2610
19	0.3437	0.4211	0.3562	0.3356	0.2642	0.2493	0.2653	0.2162	0.2058	0.2487	0.2544	0.2846
20	0.3534	0.4330	0.3663	0.3504	0.2747	0.2610	0.2773	0.2247	0.2143	0.2585	0.2649	0.2922
21	0.3600	0.4419	0.3733	0.3580	0.2789	0.2658	0.2813	0.2261	0.2161	0.2621	0.2696	0.2969
22	0.3290	0.4053	0.3418	0.3328	0.2505	0.2354	0.2445	0.1873	0.1826	0.2339	0.2460	0.2683
23	0.0794	0.0976	0.0826	0.1061	0.0768	0.0839	0.0849	0.0602	0.0609	0.0713	0.0770	0.0642

Appendix 19 Collective hourly unit demand per BFA from January to December for factory

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
1	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
2	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
3	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
4	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
5	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
6	0.0027	0.0030	0.0030	0.0032	0.0035	0.0037	0.0036	0.0034	0.0038	0.0034	0.0030	0.0031
7	0.0092	0.0101	0.0099	0.0105	0.0116	0.0124	0.0122	0.0115	0.0126	0.0113	0.0100	0.0102
8	0.1332	0.1446	0.1110	0.0850	0.1090	0.1300	0.1512	0.1527	0.1354	0.1146	0.0798	0.1230
9	0.1528	0.1682	0.1426	0.1271	0.1523	0.1750	0.1938	0.1924	0.1814	0.1562	0.1201	0.1535
10	0.1362	0.1516	0.1325	0.1224	0.1490	0.1730	0.1950	0.1948	0.1798	0.1540	0.1157	0.1410
11	0.1273	0.1422	0.1251	0.1170	0.1455	0.1705	0.1933	0.1935	0.1770	0.1511	0.1102	0.1320
12	0.0882	0.1008	0.0900	0.0843	0.1110	0.1350	0.1630	0.1665	0.1419	0.1188	0.0793	0.0944
13	0.1327	0.1507	0.1404	0.1392	0.1698	0.1979	0.2255	0.2261	0.2064	0.1763	0.1317	0.1465
14	0.1206	0.1386	0.1321	0.1337	0.1658	0.1953	0.2260	0.2278	0.2041	0.1735	0.1264	0.1366
15	0.1120	0.1287	0.1224	0.1243	0.1579	0.1877	0.2179	0.2199	0.1956	0.1658	0.1169	0.1256
16	0.1182	0.1336	0.1219	0.1187	0.1489	0.1755	0.2011	0.2020	0.1825	0.1553	0.1118	0.1269
17	0.1273	0.1423	0.1264	0.1190	0.1446	0.1677	0.1889	0.1887	0.1744	0.1494	0.1125	0.1338
18	0.1214	0.1355	0.1189	0.1101	0.1334	0.1548	0.1752	0.1753	0.1613	0.1380	0.1042	0.1267
19	0.0209	0.0232	0.0227	0.0241	0.0262	0.0281	0.0276	0.0261	0.0287	0.0256	0.0229	0.0235
20	0.0018	0.0020	0.0020	0.0021	0.0023	0.0025	0.0024	0.0023	0.0025	0.0023	0.0020	0.0020
21	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
22	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010
23	0.0009	0.0010	0.0010	0.0011	0.0012	0.0012	0.0012	0.0011	0.0013	0.0011	0.0010	0.0010

Appendix 20 Collective hourly unit demand per BFA from January to December for factory

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
1	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
2	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
3	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
4	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
5	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
6	0.0021	0.0023	0.0022	0.0021	0.0023	0.0021	0.0021	0.0019	0.0021	0.0022	0.0020	0.0023
7	0.0072	0.0080	0.0078	0.0071	0.0078	0.0070	0.0069	0.0065	0.0071	0.0076	0.0068	0.0081
8	0.1016	0.1096	0.0769	0.0516	0.0723	0.0940	0.1161	0.1195	0.0989	0.0789	0.0482	0.0878
9	0.1073	0.1177	0.0934	0.0753	0.0954	0.1145	0.1347	0.1365	0.1199	0.1007	0.0710	0.1028
10	0.0971	0.1083	0.0902	0.0774	0.0996	0.1198	0.1430	0.1456	0.1258	0.1058	0.0730	0.0975
11	0.0882	0.0989	0.0829	0.0720	0.0961	0.1173	0.1414	0.1444	0.1229	0.1029	0.0675	0.0885
12	0.0839	0.0960	0.0853	0.0793	0.1055	0.1291	0.1572	0.1611	0.1358	0.1134	0.0746	0.0896
13	0.0876	0.1008	0.0918	0.0877	0.1132	0.1374	0.1664	0.1702	0.1449	0.1211	0.0828	0.0964
14	0.0825	0.0964	0.0909	0.0905	0.1184	0.1449	0.1768	0.1813	0.1530	0.1272	0.0855	0.0942
15	0.0739	0.0865	0.0812	0.0810	0.1105	0.1373	0.1686	0.1733	0.1444	0.1195	0.0759	0.0832
16	0.0805	0.0919	0.0812	0.0759	0.1020	0.1257	0.1523	0.1559	0.1319	0.1095	0.0712	0.0850
17	0.0904	0.1014	0.0865	0.0768	0.0983	0.1182	0.1406	0.1430	0.1241	0.1043	0.0725	0.0927
18	0.0916	0.1025	0.0867	0.0743	0.0941	0.1107	0.1321	0.1346	0.1165	0.0997	0.0703	0.0936
19	0.0137	0.0152	0.0149	0.0138	0.0148	0.0134	0.0132	0.0125	0.0137	0.0145	0.0131	0.0155
20	0.0016	0.0017	0.0017	0.0015	0.0016	0.0014	0.0014	0.0013	0.0014	0.0016	0.0014	0.0017
21	0.0010	0.0011	0.0011	0.0009	0.0010	0.0007	0.0007	0.0006	0.0007	0.0010	0.0008	0.0012
22	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006
23	0.0005	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0006	0.0006

Appendix 21 Collective hourly unit demand per BFA from January to December for school

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004	0.0004	0.0003	0.0003	0.0003
1	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
2	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
3	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
5	0.0003	0.0003	0.0003	0.0034	0.0027	0.0003	0.0003	0.0003	0.0003	0.0027	0.0029	0.0003
6	0.0014	0.0016	0.0015	0.0005	0.0005	0.0022	0.0020	0.0016	0.0017	0.0005	0.0005	0.0015
7	0.0014	0.0013	0.0012	0.0030	0.0025	0.0030	0.0030	0.0030	0.0027	0.0025	0.0026	0.0012
8	0.0341	0.0298	0.0257	0.0078	0.0047	0.0057	0.0065	0.0083	0.0063	0.0050	0.0135	0.0258
9	0.0289	0.0263	0.0230	0.0079	0.0051	0.0056	0.0066	0.0084	0.0065	0.0054	0.0132	0.0231
10	0.0208	0.0193	0.0170	0.0113	0.0087	0.0090	0.0095	0.0107	0.0089	0.0089	0.0134	0.0170
11	0.0299	0.0285	0.0252	0.0107	0.0081	0.0101	0.0105	0.0116	0.0098	0.0084	0.0133	0.0253
12	0.0290	0.0274	0.0241	0.0169	0.0124	0.0108	0.0112	0.0121	0.0103	0.0125	0.0202	0.0242
13	0.0367	0.0365	0.0324	0.0085	0.0057	0.0091	0.0096	0.0109	0.0090	0.0060	0.0135	0.0326
14	0.0230	0.0217	0.0191	0.0092	0.0062	0.0073	0.0080	0.0096	0.0077	0.0066	0.0140	0.0192
15	0.0203	0.0186	0.0164	0.0085	0.0057	0.0059	0.0070	0.0092	0.0069	0.0060	0.0133	0.0164
16	0.0219	0.0199	0.0175	0.0071	0.0058	0.0065	0.0073	0.0090	0.0071	0.0060	0.0081	0.0175
17	0.0151	0.0140	0.0124	0.0060	0.0050	0.0050	0.0060	0.0079	0.0059	0.0052	0.0062	0.0124
18	0.0041	0.0045	0.0043	0.0053	0.0046	0.0046	0.0049	0.0056	0.0047	0.0047	0.0049	0.0042
19	0.0039	0.0044	0.0041	0.0032	0.0029	0.0034	0.0034	0.0034	0.0032	0.0030	0.0031	0.0041
20	0.0014	0.0015	0.0015	0.0021	0.0019	0.0015	0.0016	0.0018	0.0016	0.0020	0.0021	0.0014
21	0.0011	0.0012	0.0011	0.0010	0.0010	0.0011	0.0012	0.0013	0.0011	0.0011	0.0011	0.0011
22	0.0008	0.0008	0.0008	0.0007	0.0007	0.0008	0.0008	0.0009	0.0008	0.0008	0.0008	0.0008
23	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0005	0.0004	0.0004	0.0004	0.0004

Appendix 22 Collective hourly unit demand per BFA from January to December for hospital

Season	Winter			Spring/autumn		Summer				Spring/Autumn		Winter
Time / Month	1	2	3	4	5	6	7	8	9	10	11	12
0	0.0121	0.0012	0.0119	0.0103	0.0120	0.0145	0.0215	0.0348	0.0227	0.0142	0.0107	0.0117
1	0.0122	0.0012	0.0118	0.0097	0.0113	0.0137	0.0207	0.0341	0.0220	0.0135	0.0101	0.0115
2	0.0116	0.0012	0.0112	0.0091	0.0107	0.0131	0.0197	0.0323	0.0209	0.0128	0.0095	0.0110
3	0.0114	0.0011	0.0110	0.0091	0.0107	0.0129	0.0195	0.0321	0.0207	0.0128	0.0095	0.0108
4	0.0118	0.0012	0.0114	0.0097	0.0111	0.0140	0.0204	0.0329	0.0215	0.0131	0.0099	0.0111
5	0.0520	0.0047	0.0417	0.0185	0.0146	0.0197	0.0336	0.0608	0.0363	0.0172	0.0307	0.0417
6	0.0524	0.0048	0.0430	0.0257	0.0198	0.0246	0.0353	0.0561	0.0368	0.0221	0.0393	0.0428
7	0.0557	0.0051	0.0463	0.0344	0.0284	0.0336	0.0452	0.0677	0.0464	0.0312	0.0464	0.0459
8	0.1239	0.0116	0.1040	0.0537	0.0442	0.0551	0.0803	0.1299	0.0836	0.0481	0.0696	0.1039
9	0.1165	0.0112	0.1012	0.0599	0.0522	0.0623	0.0866	0.1346	0.0890	0.0566	0.0694	0.1010
10	0.1129	0.0110	0.0994	0.0620	0.0544	0.0653	0.0906	0.1407	0.0931	0.0590	0.0705	0.0991
11	0.1027	0.0099	0.0900	0.0548	0.0495	0.0606	0.0873	0.1400	0.0907	0.0546	0.0630	0.0897
12	0.1002	0.0098	0.0887	0.0564	0.0514	0.0618	0.0887	0.1417	0.0919	0.0566	0.0628	0.0884
13	0.0930	0.0092	0.0842	0.0588	0.0533	0.0625	0.0859	0.1323	0.0881	0.0584	0.0645	0.0838
14	0.0895	0.0089	0.0810	0.0567	0.0520	0.0605	0.0843	0.1312	0.0868	0.0571	0.0622	0.0806
15	0.0826	0.0081	0.0741	0.0491	0.0463	0.0552	0.0804	0.1298	0.0838	0.0517	0.0550	0.0737
16	0.0791	0.0077	0.0703	0.0439	0.0419	0.0513	0.0767	0.1266	0.0806	0.0472	0.0498	0.0698
17	0.0780	0.0076	0.0690	0.0426	0.0405	0.0501	0.0749	0.1235	0.0785	0.0456	0.0480	0.0686
18	0.0742	0.0071	0.0650	0.0397	0.0376	0.0468	0.0700	0.1156	0.0735	0.0421	0.0447	0.0647
19	0.0585	0.0057	0.0522	0.0350	0.0323	0.0381	0.0512	0.0766	0.0525	0.0356	0.0400	0.0518
20	0.0505	0.0048	0.0439	0.0273	0.0254	0.0305	0.0436	0.0689	0.0456	0.0286	0.0335	0.0436
21	0.0446	0.0041	0.0375	0.0190	0.0177	0.0228	0.0354	0.0600	0.0377	0.0205	0.0255	0.0372
22	0.0442	0.0040	0.0362	0.0173	0.0149	0.0193	0.0311	0.0540	0.0334	0.0175	0.0266	0.0361
23	0.0140	0.0015	0.0140	0.0122	0.0136	0.0162	0.0231	0.0365	0.0243	0.0159	0.0123	0.0137

Appendix 23 Status of power balance of Umegaoka town in various disturbance scenarios

Power balance	DRC100	DRC075	DRC050	DRC025	DRC000
BAU	OK	OK	OK	OK	OK
B1	OK	OK	OK	OK	FAIL
B2	OK	OK	OK	FAIL	FAIL
B3	OK	OK	FAIL	FAIL	FAIL
B4	OK	FAIL	FAIL	FAIL	FAIL
B5	FAIL	FAIL	FAIL	FAIL	FAIL
C1	OK	OK	OK	OK	FAIL
C2	OK	OK	OK	FAIL	FAIL
D1	OK	FAIL	FAIL	FAIL	FAIL
D2	FAIL	FAIL	FAIL	FAIL	FAIL
E1	OK	-	-	-	-
E2	FAIL	FAIL	FAIL	FAIL	FAIL
E3	-	-	-	-	-

Appendix 24 Performance data of functionality indicators of Umegaoka town

Demand users' convenience			Component unit							Cost of electric energy (yen/kWh)		
		System	Residential	Office	Commercial	Hotel	Factory	School	Hospital			System
DRC100	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC100	BAU	10.3942
	B1	0.9968	0.9876	0.9951	0.9989	0.0000	0.9994	0.9975	0.9988		B1	10.8317
	B2	0.9950	0.9794	0.9927	0.9982	0.0000	0.9993	0.9955	0.9986		B2	11.1798
	B3	0.9918	0.9558	0.9916	0.9974	0.0000	0.9993	0.9945	0.9985		B3	12.1171
	B4	0.9872	0.9226	0.9900	0.9968	0.0000	0.9992	0.9936	0.9979		B4	14.1548
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	0.9977	0.9930	0.9956	0.9990	0.0000	0.9994	0.9977	0.9990		C1	10.7540
	C2	0.9966	0.9857	0.9950	0.9989	0.0000	0.9994	0.9975	0.9988		C2	11.2616
	D1	0.9894	0.9376	0.9910	0.9972	0.0000	0.9992	0.9942	0.9983		D1	13.5482
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	0.9894	0.9376	0.9910	0.9972	0.0000	0.9992	0.9942	0.9983		E1	13.5482
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	-	-	-	-	-	-	-	-		E3	-
DRC075	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC075	BAU	10.3942
	B1	0.9973	0.9881	0.9962	0.9991	0.0000	0.9996	0.9981	0.9990		B1	10.8317
	B2	0.9957	0.9806	0.9943	0.9985	0.0000	0.9994	0.9964	0.9989		B2	11.1798
	B3	0.9926	0.9578	0.9933	0.9979	0.0000	0.9994	0.9957	0.9988		B3	12.1171
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	0.9980	0.9929	0.9966	0.9992	0.0000	0.9996	0.9982	0.9992		C1	10.7540
	C2	0.9971	0.9864	0.9963	0.9992	0.0000	0.9996	0.9982	0.9991		C2	11.2616
	D1	-	-	-	-	-	-	-	-		D1	-
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	-	-	-	-	-	-	-	-		E3	-
DRC050	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC050	BAU	10.3942
	B1	0.9978	0.9891	0.9975	0.9994	0.0000	0.9997	0.9987	0.9993		B1	10.8317
	B2	0.9965	0.9821	0.9960	0.9989	0.0000	0.9996	0.9975	0.9992		B2	11.1798
	B3	-	-	-	-	-	-	-	-		B3	-
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	0.9984	0.9932	0.9976	0.9995	0.0000	0.9997	0.9988	0.9994		C1	10.7540
	C2	0.9976	0.9875	0.9974	0.9994	0.0000	0.9997	0.9987	0.9993		C2	11.2616
	D1	-	-	-	-	-	-	-	-		D1	-
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	-	-	-	-	-	-	-	-		E3	-
DRC025	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC025	BAU	10.3942
	B1	0.9983	0.9901	0.9984	0.9997	0.0000	0.9999	0.9992	0.9995		B1	10.8317
	B2	-	-	-	-	-	-	-	-		B2	-
	B3	-	-	-	-	-	-	-	-		B3	-
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	0.9989	0.9942	0.9988	0.9997	0.0000	0.9999	0.9994	0.9997		C1	10.7540
	C2	-	-	-	-	-	-	-	-		C2	-
	D1	-	-	-	-	-	-	-	-		D1	-
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	-	-	-	-	-	-	-	-		E3	-
DRC000	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC000	BAU	10.3942
	B1	-	-	-	-	-	-	-	-		B1	-
	B2	-	-	-	-	-	-	-	-		B2	-
	B3	-	-	-	-	-	-	-	-		B3	-
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	-	-	-	-	-	-	-	-		C1	-
	C2	-	-	-	-	-	-	-	-		C2	-
	D1	-	-	-	-	-	-	-	-		D1	-
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	-	-	-	-	-	-	-	-		E3	-

Appendix 25 Performance data of redundancy indicators of Umegaoka town

Redundancy			Generation type			Generation unit							
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage
DRC100	BAU	0.5575	0.5319	1.0000	0.0172	0.8703	0.5623	0.2186	0.0000	0.7657	1.0000	0.0172	1.0000
	B1	0.5302	0.4851	0.9993	0.0172	0.8287	0.4959	0.1780	0.0000	0.7113	1.0000	0.0172	0.9991
	B2	0.5167	0.4605	0.9978	0.0172	0.8071	0.4646	0.1558	0.0000	0.6731	1.0000	0.0172	0.9973
	B3	0.4888	0.4053	0.9954	0.0172	0.7567	0.4192	0.1025	0.0000	0.5200	1.0000	0.0172	0.9945
	B4	0.4434	0.3020	0.9854	0.0172	0.5521	0.3480	0.0000	0.0000	0.4190	0.9970	0.0172	0.9829
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.5415	0.5048	1.0000	0.0172	0.8448	0.4873	0.1046	0.0000	0.7300	1.0000	0.0172	1.0000
	C2	0.5254	0.4765	0.9988	0.0172	0.8155	0.4258	0.0000	0.0000	0.6652	1.0000	0.0172	0.9985
	D1	0.4623	0.3476	0.9907	0.0172	0.6368	0.2951	0.0000	0.0000	0.4483	1.0000	0.0172	0.9887
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	0.4623	0.3476	0.9907	0.0172	0.6368	0.2951	0.0000	0.0000	0.4483	1.0000	0.0172	0.9887
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC075	BAU	0.5575	0.5319	1.0000	0.0172	0.8703	0.5623	0.2186	0.0000	0.7657	1.0000	0.0172	1.0000
	B1	0.5302	0.4851	0.9993	0.0172	0.8287	0.4959	0.1780	0.0000	0.7113	1.0000	0.0172	0.9991
	B2	0.5167	0.4605	0.9978	0.0172	0.8071	0.4646	0.1558	0.0000	0.6731	1.0000	0.0172	0.9973
	B3	0.4888	0.4053	0.9954	0.0172	0.7567	0.4192	0.1025	0.0000	0.5200	1.0000	0.0172	0.9945
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.5415	0.5048	1.0000	0.0172	0.8448	0.4873	0.1046	0.0000	0.7300	1.0000	0.0172	1.0000
	C2	0.5254	0.4765	0.9988	0.0172	0.8155	0.4258	0.0000	0.0000	0.6652	1.0000	0.0172	0.9985
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC050	BAU	0.5575	0.5319	1.0000	0.0172	0.8703	0.5623	0.2186	0.0000	0.7657	1.0000	0.0172	1.0000
	B1	0.5302	0.4851	0.9993	0.0172	0.8287	0.4959	0.1780	0.0000	0.7113	1.0000	0.0172	0.9991
	B2	0.5167	0.4605	0.9978	0.0172	0.8071	0.4646	0.1558	0.0000	0.6731	1.0000	0.0172	0.9973
	B3	-	-	-	-	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.5415	0.5048	1.0000	0.0172	0.8448	0.4873	0.1046	0.0000	0.7300	1.0000	0.0172	1.0000
	C2	0.5254	0.4765	0.9987	0.0172	0.8155	0.4258	0.0000	0.0000	0.6652	1.0000	0.0172	0.9984
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC025	BAU	0.5575	0.5319	1.0000	0.0172	0.8703	0.5623	0.2186	0.0000	0.7657	1.0000	0.0172	1.0000
	B1	0.5302	0.4851	0.9993	0.0172	0.8287	0.4959	0.1780	0.0000	0.7113	1.0000	0.0172	0.9992
	B2	-	-	-	-	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.5415	0.5048	1.0000	0.0172	0.8448	0.4873	0.1046	0.0000	0.7300	1.0000	0.0172	1.0000
	C2	-	-	-	-	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC000	BAU	0.5575	0.5319	1.0000	0.0172	0.8703	0.5623	0.2186	0.0000	0.7657	1.0000	0.0172	1.0000
	B1	-	-	-	-	-	-	-	-	-	-	-	-
	B2	-	-	-	-	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	-	-	-	-	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-

Redundancy			Network unit		
		System	Feeder	Primary	Bypass
DRC100	BAU	0.9947	0.9935	0.9965	0.0000
	B1	0.9947	0.9935	0.9966	0.0000
	B2	0.9948	0.9936	0.9966	0.0000
	B3	0.9949	0.9938	0.9966	0.0000
	B4	0.9952	0.9941	0.9967	0.0000
	B5	-	-	-	-
	C1	0.9947	0.9935	0.9965	0.0000
	C2	0.9948	0.9936	0.9966	0.0000
	D1	0.9951	0.9940	0.9967	0.0000
	D2	-	-	-	-
	E1	0.9951	0.9940	0.9967	0.0000
	E2	-	-	-	-
	E3	-	-	-	-
DRC075	BAU	0.9947	0.9935	0.9965	0.0000
	B1	0.9947	0.9935	0.9966	0.0000
	B2	0.9948	0.9936	0.9966	0.0000
	B3	0.9949	0.9938	0.9966	0.0000
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.9947	0.9935	0.9965	0.0000
	C2	0.9948	0.9936	0.9966	0.0000
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-
DRC050	BAU	0.9947	0.9935	0.9965	0.0000
	B1	0.9947	0.9935	0.9966	0.0000
	B2	0.9948	0.9936	0.9966	0.0000
	B3	-	-	-	-
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.9947	0.9935	0.9965	0.0000
	C2	0.9948	0.9936	0.9966	0.0000
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-
DRC025	BAU	0.9947	0.9935	0.9965	0.0000
	B1	0.9947	0.9935	0.9966	0.0000
	B2	-	-	-	-
	B3	-	-	-	-
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.9947	0.9935	0.9965	0.0000
	C2	-	-	-	-
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-
DRC000	BAU	0.9947	0.9935	0.9965	0.0000
	B1	-	-	-	-
	B2	-	-	-	-
	B3	-	-	-	-
	B4	-	-	-	-
	B5	-	-	-	-
	C1	-	-	-	-
	C2	-	-	-	-
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-

Redundancy			Consumption unit						
		System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.9972	0.7902	0.7436	0.7017	0.0000	0.6111	0.8021	0.2222
	B1	0.9851	0.7835	0.7279	0.6880	0.0000	0.5909	0.7926	0.2164
	B2	0.9767	0.7789	0.7161	0.6742	0.0000	0.5771	0.7822	0.2157
	B3	0.9584	0.7658	0.7111	0.6719	0.0000	0.5768	0.7772	0.2151
	B4	0.9332	0.7477	0.7052	0.6695	0.0000	0.5762	0.7733	0.2122
	B5	-	-	-	-	-	-	-	-
	C1	0.9893	0.7863	0.7295	0.6883	0.0000	0.5911	0.7933	0.2176
	C2	0.9836	0.7824	0.7276	0.6879	0.0000	0.5903	0.7925	0.2162
	D1	0.9449	0.7560	0.7088	0.6716	0.0000	0.5762	0.7757	0.2142
	D2	-	-	-	-	-	-	-	-
	E1	0.9640	0.3780	0.7443	0.6467	0.0000	0.6178	0.7759	0.2500
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC075	BAU	0.9972	0.7902	0.7436	0.7017	0.0000	0.6111	0.8021	0.2222
	B1	0.9824	0.7816	0.7271	0.6878	0.0000	0.5906	0.7923	0.2159
	B2	0.9727	0.7762	0.7147	0.6736	0.0000	0.5767	0.7809	0.2154
	B3	0.9494	0.7594	0.7092	0.6717	0.0000	0.5770	0.7759	0.2144
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.9873	0.7850	0.7288	0.6882	0.0000	0.5910	0.7930	0.2169
	C2	0.9810	0.7805	0.7278	0.6879	0.0000	0.5903	0.7928	0.2161
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC050	BAU	0.9972	0.7902	0.7436	0.7017	0.0000	0.6111	0.8021	0.2222
	B1	0.9782	0.7786	0.7271	0.6878	0.0000	0.5906	0.7924	0.2156
	B2	0.9654	0.7710	0.7134	0.6735	0.0000	0.5765	0.7801	0.2149
	B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.9842	0.7828	0.7284	0.6882	0.0000	0.5909	0.7930	0.2165
	C2	0.9760	0.7770	0.7270	0.6878	0.0000	0.5908	0.7924	0.2154
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC025	BAU	0.9972	0.7902	0.7436	0.7017	0.0000	0.6111	0.8021	0.2222
	B1	0.9650	0.7694	0.7233	0.6867	0.0000	0.5904	0.7905	0.2133
	B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.9772	0.7779	0.7274	0.6877	0.0000	0.5906	0.7927	0.2157
	C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B1	-	-	-	-	-	-	-	-
	B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-

Appendix 26 Performance data of adaptability indicators of Umegaoka town

Adaptability			Generation type			Generation unit								Adaptability			Network unit			Adaptability			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.6633	0.7007	1.0000	0.0000	1.0000	0.7917	0.3958	0.1125	0.8750	1.0000	0.0000	1.0000	DRC100	BAU	1.0000	1.0000	1.0000	1.0000	DRC100	BAU	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B1	0.7401	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B2	0.7369	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B3	0.6705	0.7257	1.0000	0.0000	0.8750	0.8750	0.4375	0.2625	0.8750	1.0000	0.0000	1.0000		B3	1.0000	1.0000	1.0000	1.0000		B3	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B4	0.7170	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B4	1.0000	1.0000	1.0000	1.0000		B4	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.7633	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	C2	0.7822	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	D1	0.5653	0.5389	1.0000	0.0000	0.7917	0.5000	0.2500	0.0000	0.5833	1.0000	0.0000	1.0000		D1	1.0000	1.0000	1.0000	1.0000		D1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	0.5653	0.5389	1.0000	0.0000	0.7917	0.5000	0.2500	0.0000	0.5833	1.0000	0.0000	1.0000		E1	1.0000	1.0000	1.0000	1.0000		E1	0.9759	0.3880	0.6154	0.5373	0.0000	0.3264	0.7917	0.0500
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC075	BAU	0.6633	0.7007	1.0000	0.0000	1.0000	0.7917	0.3958	0.1125	0.8750	1.0000	0.0000	1.0000	DRC075	BAU	1.0000	1.0000	1.0000	1.0000	DRC075	BAU	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B1	0.7401	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B2	0.6372	0.6640	1.0000	0.0000	1.0000	0.6250	0.3125	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B3	0.7299	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B3	1.0000	1.0000	1.0000	1.0000		B3	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.7633	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	C2	0.7822	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC050	BAU	0.6336	0.6544	1.0000	0.0000	1.0000	0.7917	0.2083	0.0000	0.8750	1.0000	0.0000	1.0000	DRC050	BAU	1.0000	1.0000	1.0000	1.0000	DRC050	BAU	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B1	0.7401	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B2	0.7369	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B3	-	-	-	-	-	-	-	-	-	-	-	-		B3	-	-	-	-		B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.6779	0.7263	1.0000	0.0000	0.9583	0.7917	0.3958	0.1000	0.8750	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	C2	0.6241	0.6417	1.0000	0.0000	0.9167	0.5833	0.2917	0.0000	0.7917	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC025	BAU	0.7458	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000	DRC025	BAU	1.0000	1.0000	1.0000	1.0000	DRC025	BAU	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B1	0.7401	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	B2	-	-	-	-	-	-	-	-	-	-	-	-		B2	-	-	-	-		B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-		B3	-	-	-	-		B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.7473	0.8370	1.0000	0.0000	1.0000	0.9583	0.4792	0.2875	0.9583	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.9755	0.7902	0.5949	0.5613	0.0000	0.3056	0.8021	0.0444
	C2	-	-	-	-	-	-	-	-	-	-	-	-		C2	-	-	-	-		C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.6718	0.7140	1.0000	0.0000	1.0000	0.7917	0.3958	0.2250	0.8750	1.0000	0.0000	1.0000	DRC000	BAU	1.0000	1.0000	1.0000	1.0000	DRC000	BAU	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B1	-	-	-	-	-	-	-	-	-	-	-	-		B1	-	-	-	-		B1	-	-	-	-	-	-	-	-
	B2	-	-	-	-	-	-	-	-	-	-	-	-		B2	-	-	-	-		B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-		B3	-	-	-	-		B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	-	-	-	-	-	-	-	-	-	-	-	-		C1	-	-	-	-		C1	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-	-	-	-	-		C2	-	-	-	-		C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-

Appendix 27 Performance data of reliability indicators of Umegaoka town

Reliability			Generation type			Generation unit							
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage
DRC100	BAU	0.8236	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8239	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8241	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	0.8246	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B4	0.8255	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8245	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8255	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	0.8264	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	0.7647	0.8205	0.8333	0.5000	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.5000	0.8333
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC075	BAU	0.8236	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8239	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8241	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	0.8246	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8245	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8255	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC050	BAU	0.8236	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8239	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8241	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	-	-	-	-	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8245	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8255	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC025	BAU	0.8236	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8239	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	-	-	-	-	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8245	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	-	-	-	-	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-
DRC000	BAU	0.8236	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	-	-	-	-	-	-	-	-	-	-	-	-
	B2	-	-	-	-	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	-	-	-	-	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-

Reliability			Network unit		
		System	Feeder	Primary	Bypass
DRC100	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	0.8636	0.8333	0.9091	0.0000
	B4	0.8636	0.8333	0.9091	0.0000
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	0.8636	0.8333	0.9091	0.0000
	D2	-	-	-	-
	E1	0.8271	0.8333	0.8176	0.0000
	E2	-	-	-	-
	E3	-	-	-	-
DRC075	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	0.8636	0.8333	0.9091	0.0000
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-
DRC050	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	-	-	-	-
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-
DRC025	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	-	-	-	-
	B3	-	-	-	-
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	-	-	-	-
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-
DRC000	BAU	0.8636	0.8333	0.9091	0.0000
	B1	-	-	-	-
	B2	-	-	-	-
	B3	-	-	-	-
	B4	-	-	-	-
	B5	-	-	-	-
	C1	-	-	-	-
	C2	-	-	-	-
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	-	-	-	-

Reliability			Consumption unit						
		System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B2	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B3	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B4	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B5	-	-	-	-	-	-	-	-
	C1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	C2	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	D1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	D2	-	-	-	-	-	-	-	-
	E1	0.4285	0.3788	0.7511	0.6928	0.0000	0.5724	0.8166	0.2383
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC075	BAU	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B2	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B3	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	C2	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC050	BAU	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B2	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	C2	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC025	BAU	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.7688	0.7731	0.7477	0.7202	0.0000	0.6818	0.8288	0.2296
	B1	-	-	-	-	-	-	-	-
	B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-

Appendix 28 Performance data of vulnerability indicators of Umegaoka town

Vulnerability			Generation type			Generation unit								Vulnerability			Network unit			Vulnerability			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.3722	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC100	BAU	0.3660	0.4300	0.2700	0.0000	DRC100	BAU	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B1	0.3679	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B2	0.3655	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B3	0.3603	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B4	0.3506	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B4	0.3660	0.4300	0.2700	0.0000		B4	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.3742	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	C2	0.3764	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	D1	0.3632	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	0.3817	0.4500	0.4300	0.1100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.1100	0.4300		E1	0.4080	0.4300	0.3751	0.0000		E1	0.8426	0.8870	0.5880	0.6419	0.0000	0.5354	0.5263	0.2888
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC075	BAU	0.3722	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC075	BAU	0.3660	0.4300	0.2700	0.0000	DRC075	BAU	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B1	0.3679	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B2	0.3655	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B3	0.3603	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.3742	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	C2	0.3764	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC050	BAU	0.3722	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC050	BAU	0.3660	0.4300	0.2700	0.0000	DRC050	BAU	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B1	0.3679	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B2	0.3655	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B3	-	-	-	-	-	-	-	-	-	-	-	-		B3	-	-	-	-		B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.3742	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	C2	0.3764	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC025	BAU	0.3722	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC025	BAU	0.3660	0.4300	0.2700	0.0000	DRC025	BAU	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B1	0.3679	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B2	-	-	-	-	-	-	-	-	-	-	-	-		B2	-	-	-	-		B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-		B3	-	-	-	-		B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.3742	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	C2	-	-	-	-	-	-	-	-	-	-	-	-		C2	-	-	-	-		C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.3722	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC000	BAU	0.3660	0.4300	0.2700	0.0000	DRC000	BAU	0.5724	0.5749	0.5885	0.6128	0.0000	0.5463	0.5000	0.2826
	B1	-	-	-	-	-	-	-	-	-	-	-	-		B1	-	-	-	-		B1	-	-	-	-	-	-	-	-
	B2	-	-	-	-	-	-	-	-	-	-	-	-		B2	-	-	-	-		B2	-	-	-	-	-	-	-	-
	B3	-	-	-	-	-	-	-	-	-	-	-	-		B3	-	-	-	-		B3	-	-	-	-	-	-	-	-
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	-	-	-	-	-	-	-	-	-	-	-	-		C1	-	-	-	-		C1	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-	-	-	-	-		C2	-	-	-	-		C2	-	-	-	-	-	-	-	-
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-

Appendix 29 Status of power balance of Toyosu town in various disturbance scenarios

Power balance	DRC100	DRC075	DRC050	DRC025	DRC000
BAU	OK	OK	OK	OK	OK
B1	OK	OK	OK	OK	OK
B2	OK	OK	OK	OK	OK
B3	OK	OK	OK	OK	OK
B4	OK	OK	OK	FAIL	FAIL
B5	OK	OK	FAIL	FAIL	FAIL
C1	OK	OK	OK	OK	OK
C2	OK	OK	OK	OK	OK
D1	OK	OK	OK	OK	FAIL
D2	OK	OK	OK	FAIL	FAIL
E1	OK	-	-	-	-
E2	OK	OK	OK	FAIL	FAIL
E3	OK	OK	OK	FAIL	FAIL

Appendix 30 Performance data of functionality indicators of Toyosu town

Demand users' convenience			Component unit							**Cost of electric energy (yen/kWh)**		
		System	Residential	Office	Commercial	Hotel	Factory	School	Hospital			System
DRC100	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC100	BAU	7.7750
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	8.5198
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.0429
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.2969
	B4	0.8984	0.9120	0.8724	0.8728	0.0000	0.9165	0.7369	0.9941		B4	15.6267
	B5	0.8515	0.8817	0.7867	0.8104	0.0000	0.8378	0.7066	0.9940		B5	21.8628
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.3413
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.1197
	D1	0.9606	0.9628	0.9543	0.9471	0.0000	0.9969	0.8552	0.9970		D1	13.0577
	D2	0.8595	0.8854	0.8045	0.8222	0.0000	0.8514	0.7066	0.9939		D2	20.3655
	E1	0.9606	0.9628	0.9543	0.9471	0.0000	0.9969	0.8552	0.9970		E1	13.0577
	E2	0.9561	0.9756	0.9489	0.9389	0.0000	0.9764	0.8571	0.9966		E2	13.0577
	E3	0.9561	0.9756	0.9489	0.9389	0.0000	0.9764	0.8571	0.9966		E3	13.0577
DRC075	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC075	BAU	7.7750
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	8.5198
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.0429
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.2969
	B4	0.9142	0.9294	0.8870	0.8930	0.0000	0.9171	0.7994	0.9955		B4	15.6267
	B5	0.8795	0.9098	0.8137	0.8426	0.0000	0.8626	0.7876	0.9956		B5	21.8628
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.3413
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.1197
	D1	0.9672	0.9690	0.9595	0.9552	0.0000	0.9965	0.8852	0.9977		D1	13.0577
	D2	0.8896	0.9158	0.8338	0.8569	0.0000	0.8765	0.7965	0.9956		D2	20.3655
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	0.9645	0.9796	0.9556	0.9508	0.0000	0.9810	0.8888	0.9974		E2	13.0577
	E3	0.9645	0.9796	0.9556	0.9508	0.0000	0.9810	0.8888	0.9974		E3	13.0577
DRC050	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC050	BAU	7.7750
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	8.5198
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.0429
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.2969
	B4	0.9364	0.9520	0.9080	0.9195	0.0000	0.9321	0.8695	0.9971		B4	15.6267
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.3413
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.1197
	D1	0.9740	0.9761	0.9660	0.9643	0.0000	0.9965	0.9121	0.9981		D1	13.0577
	D2	0.9066	0.9319	0.8492	0.8767	0.0000	0.8903	0.8487	0.9970		D2	20.3655
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	0.9727	0.9836	0.9627	0.9622	0.0000	0.9859	0.9179	0.9983		E2	13.0577
	E3	0.9727	0.9836	0.9627	0.9622	0.0000	0.9859	0.9179	0.9983		E3	13.0577
DRC025	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC025	BAU	7.7750
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	8.5198
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.0429
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.2969
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.3413
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.1197
	D1	0.9817	0.9840	0.9736	0.9746	0.0000	0.9962	0.9436	0.9987		D1	13.0577
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	-	-	-	-	-	-	-	-		E3	-
DRC000	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC000	BAU	7.7750
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	8.5198
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.0429
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.2969
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.3413
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.1197
	D1	-	-	-	-	-	-	-	-		D1	-
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	-	-	-	-	-	-	-	-		E3	-

Appendix 31 Performance data of redundancy indicators of Toyosu town

Redundancy			Generation type			Generation unit								Redundancy			Network unit			Redundancy			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.6061	0.5085	0.9998	0.0133	0.7984	0.5158	0.3893	0.0083	0.5861	1.0000	0.0133	0.9997	DRC100	BAU	0.9133	0.8962	0.9390	0.0000	DRC100	BAU	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B1	0.5792	0.4639	0.9918	0.0133	0.7007	0.5069	0.3353	0.0000	0.5181	1.0000	0.0133	0.9897		B1	0.9150	0.8989	0.9390	0.0000		B1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B2	0.5661	0.4418	0.9847	0.0133	0.6433	0.5095	0.2928	0.0000	0.5008	1.0000	0.0133	0.9807		B2	0.9162	0.9010	0.9390	0.0000		B2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B3	0.5261	0.3851	0.9452	0.0133	0.5500	0.4813	0.1736	0.0000	0.4694	0.9980	0.0133	0.9312		B3	0.9174	0.9029	0.9390	0.0000		B3	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B4	0.4754	0.3108	0.8632	0.0133	0.4965	0.3667	0.0647	0.0000	0.4514	0.9342	0.0133	0.8444		B4	0.9236	0.9099	0.9441	0.0000		B4	0.8241	0.6035	0.6885	0.6238	0.0000	0.2402	0.6395	0.1990
	B5	0.4759	0.2712	0.8785	0.0133	0.4875	0.2990	0.0000	0.0000	0.4333	0.9524	0.0133	0.8589		B5	0.9328	0.9202	0.9518	0.0000		B5	0.7561	0.5670	0.6161	0.5745	0.0000	0.1964	0.6121	0.1985
	C1	0.5900	0.4819	0.9965	0.0133	0.7395	0.5012	0.2311	0.0000	0.5261	1.0000	0.0133	0.9956		C1	0.9139	0.8971	0.9390	0.0000		C1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	C2	0.5744	0.4557	0.9900	0.0133	0.6618	0.4877	0.0764	0.0000	0.5164	1.0000	0.0133	0.9873		C2	0.9153	0.8995	0.9390	0.0000		C2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	D1	0.4908	0.3362	0.8925	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9349	0.0133	0.8813		D1	0.9184	0.9038	0.9402	0.0000		D1	0.9183	0.6778	0.7554	0.6825	0.0000	0.2890	0.7111	0.2078
	D2	0.4789	0.2881	0.8766	0.0133	0.4965	0.2388	0.0000	0.0000	0.4514	0.9568	0.0133	0.8553		D2	0.9306	0.9178	0.9499	0.0000		D2	0.7672	0.5710	0.6308	0.5833	0.0000	0.2032	0.6119	0.1983
	E1	0.4908	0.3362	0.8925	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9349	0.0133	0.8813		E1	0.9184	0.9038	0.9402	0.0000		E1	0.9183	0.6778	0.7554	0.6825	0.0000	0.2890	0.7111	0.2078
	E2	0.4906	0.3362	0.8916	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9327	0.0133	0.8807		E2	0.9184	0.9038	0.9402	0.0000		E2	0.9078	0.3944	0.7011	0.6453	0.0000	0.5225	0.7193	0.1624
	E3	0.4906	0.3362	0.8916	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9327	0.0133	0.8807		E3	0.9129	0.9058	0.9236	0.0000		E3	0.9078	0.3944	0.7011	0.6453	0.0000	0.5225	0.7193	0.1624
DRC075	BAU	0.6061	0.5085	0.9998	0.0133	0.7984	0.5158	0.3893	0.0083	0.5861	1.0000	0.0133	0.9997	DRC075	BAU	0.9133	0.8962	0.9390	0.0000	DRC075	BAU	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B1	0.5792	0.4639	0.9919	0.0133	0.7007	0.5069	0.3353	0.0000	0.5181	1.0000	0.0133	0.9897		B1	0.9150	0.8989	0.9390	0.0000		B1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B2	0.5661	0.4418	0.9848	0.0133	0.6433	0.5095	0.2928	0.0000	0.5008	1.0000	0.0133	0.9807		B2	0.9162	0.9010	0.9390	0.0000		B2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B3	0.5261	0.3851	0.9449	0.0133	0.5500	0.4813	0.1736	0.0000	0.4694	0.9980	0.0133	0.9307		B3	0.9174	0.9029	0.9390	0.0000		B3	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B4	0.4753	0.3108	0.8626	0.0133	0.4965	0.3667	0.0647	0.0000	0.4514	0.9342	0.0133	0.8436		B4	0.9237	0.9100	0.9442	0.0000		B4	0.8081	0.5949	0.6705	0.6123	0.0000	0.2250	0.6370	0.1987
	B5	0.4761	0.2712	0.8790	0.0133	0.4875	0.2990	0.0000	0.0000	0.4333	0.9525	0.0133	0.8595		B5	0.9324	0.9196	0.9516	0.0000		B5	0.7397	0.5660	0.5871	0.5596	0.0000	0.1861	0.6184	0.1993
	C1	0.5900	0.4819	0.9965	0.0133	0.7395	0.5012	0.2311	0.0000	0.5261	1.0000	0.0133	0.9956		C1	0.9139	0.8971	0.9390	0.0000		C1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	C2	0.5744	0.4557	0.9899	0.0133	0.6618	0.4877	0.0764	0.0000	0.5164	1.0000	0.0133	0.9873		C2	0.9153	0.8995	0.9390	0.0000		C2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	D1	0.4906	0.3362	0.8917	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9335	0.0133	0.8807		D1	0.9184	0.9038	0.9403	0.0000		D1	0.9110	0.6721	0.7494	0.6775	0.0000	0.2877	0.7065	0.2076
	D2	0.4785	0.2881	0.8756	0.0133	0.4965	0.2388	0.0000	0.0000	0.4514	0.9568	0.0133	0.8540		D2	0.9305	0.9176	0.9500	0.0000		D2	0.7594	0.5759	0.6096	0.5741	0.0000	0.1959	0.6251	0.1990
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4908	0.3362	0.8923	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9337	0.0133	0.8813		E2	0.9183	0.9037	0.9402	0.0000		E2	0.9016	0.3910	0.6953	0.6419	0.0000	0.5212	0.7171	0.1622
	E3	0.4908	0.3362	0.8923	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9337	0.0133	0.8813		E3	0.9128	0.9057	0.9235	0.0000		E3	0.9016	0.3910	0.6953	0.6419	0.0000	0.5212	0.7171	0.1622
DRC050	BAU	0.6061	0.5085	0.9998	0.0133	0.7984	0.5158	0.3893	0.0083	0.5861	1.0000	0.0133	0.9997	DRC050	BAU	0.9133	0.8962	0.9390	0.0000	DRC050	BAU	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B1	0.5792	0.4639	0.9918	0.0133	0.7007	0.5069	0.3353	0.0000	0.5181	1.0000	0.0133	0.9897		B1	0.9150	0.8989	0.9390	0.0000		B1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B2	0.5661	0.4418	0.9848	0.0133	0.6433	0.5095	0.2928	0.0000	0.5008	1.0000	0.0133	0.9807		B2	0.9162	0.9010	0.9390	0.0000		B2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B3	0.5261	0.3851	0.9446	0.0133	0.5500	0.4813	0.1736	0.0000	0.4694	0.9980	0.0133	0.9305		B3	0.9173	0.9029	0.9390	0.0000		B3	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B4	0.4758	0.3108	0.8641	0.0133	0.4965	0.3667	0.0647	0.0000	0.4514	0.9342	0.0133	0.8455		B4	0.9236	0.9098	0.9443	0.0000		B4	0.7925	0.5923	0.6449	0.5988	0.0000	0.2107	0.6412	0.1992
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.5900	0.4819	0.9966	0.0133	0.7395	0.5012	0.2311	0.0000	0.5261	1.0000	0.0133	0.9956		C1	0.9140	0.8974	0.9390	0.0000		C1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	C2	0.5744	0.4557	0.9899	0.0133	0.6618	0.4877	0.0764	0.0000	0.5164	1.0000	0.0133	0.9872		C2	0.9153	0.8995	0.9390	0.0000		C2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	D1	0.4906	0.3362	0.8918	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9335	0.0133	0.8808		D1	0.9184	0.9038	0.9403	0.0000		D1	0.8971	0.6621	0.7387	0.6685	0.0000	0.2858	0.6921	0.2050
	D2	0.4771	0.2881	0.8702	0.0133	0.4965	0.2388	0.0000	0.0000	0.4514	0.9570	0.0133	0.8471		D2	0.9297	0.9164	0.9496	0.0000		D2	0.6999	0.5454	0.5414	0.5308	0.0000	0.1638	0.6069	0.1986
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4907	0.3362	0.8921	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9345	0.0133	0.8808		E2	0.9183	0.9037	0.9402	0.0000		E2	0.8880	0.3832	0.6845	0.6338	0.0000	0.5189	0.7070	0.1621
	E3	0.4907	0.3362	0.8921	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9345	0.0133	0.8808		E3	0.9128	0.9056	0.9235	0.0000		E3	0.8880	0.3832	0.6845	0.6338	0.0000	0.5189	0.7070	0.1621
DRC025	BAU	0.6061	0.5085	0.9998	0.0133	0.7984	0.5158	0.3893	0.0083	0.5861	1.0000	0.0133	0.9997	DRC025	BAU	0.9133	0.8962	0.9390	0.0000	DRC025	BAU	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B1	0.5792	0.4639	0.9918	0.0133	0.7007	0.5069	0.3353	0.0000	0.5181	1.0000	0.0133	0.9896		B1	0.9150	0.8989	0.9390	0.0000		B1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B2	0.5661	0.4418	0.9847	0.0133	0.6433	0.5095	0.2928	0.0000	0.5008	1.0000	0.0133	0.9806		B2	0.9162	0.9010	0.9390	0.0000		B2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B3	0.5262	0.3851	0.9446	0.0133	0.5500	0.4813	0.1736	0.0000	0.4694	0.9980	0.0133	0.9304		B3	0.9173	0.9029	0.9390	0.0000		B3	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.5900	0.4819	0.9965	0.0133	0.7395	0.5012	0.2311	0.0000	0.5261	1.0000	0.0133	0.9956		C1	0.9139	0.8971	0.9390	0.0000		C1	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	C2	0.5744	0.4557	0.9899	0.0133	0.6618	0.4877	0.0764	0.0000	0.5164	1.0000	0.0133	0.9872		C2	0.9153	0.8995	0.9390	0.0000		C2	0.9834	0.7390	0.7895	0.7212	0.0000	0.2917	0.8000	0.2188
	D1	0.4906	0.3362	0.8919	0.0133	0.5185	0.3384	0.0000	0.0000	0.4694	0.9334	0.0133	0.8808		D1	0.9184	0.9038	0.9403	0.0000		D1	0.8620	0.6366	0.7109	0.6450	0.0000	0.2779	0.6611	0.2007
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.6061	0.5085	0.9998	0.0133	0.7984	0.5158	0.3893	0.0083	0.5861	1.0000	0.0133	0.9997	DRC000	BAU	0.9133	0.8962	0.9390	0.0000	DRC000	BAU	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B1	0.5792	0.4639	0.9917	0.0133	0.7007	0.5069	0.3353	0.0000	0.5181	1.0000	0.0133	0.9895		B1	0.9150	0.8990	0.9390	0.0000		B1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B2	0.5661	0.4418	0.9847	0.0133	0.6433	0.5095	0.2928	0.0000	0.5008	1.0000	0.0133	0.9806		B2	0.9162	0.9010	0.9390	0.0000		B2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B3	0.5262	0.3851	0.9444	0.0133	0.5500	0.4813	0.1736	0.0000	0.4694	0.9980	0.0133	0.9302		B3	0.9173	0.9029	0.9390	0.0000		B3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.5900	0.4819	0.9965	0.0133	0.7395	0.5012	0.2311	0.0000	0.5261	1.0000	0.0133	0.9956		C1	0.9140	0.8973	0.9390	0.0000		C1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	C2	0.5744	0.4557	0.9898	0.0133	0.6618	0.4877	0.0764	0.0000	0.5164	1.0000	0.0133	0.9871		C2	0.9153	0.8995	0.9390	0.0000		C2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-

Appendix 32 Performance data of adaptability indicators of Toyosu town

Adaptability			Generation type			Generation unit								Adaptability			Network unit			Adaptability			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.8524	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000	DRC100	BAU	1.0000	1.0000	1.0000	1.0000	DRC100	BAU	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B1	0.7057	0.6309	1.0000	0.0000	1.0000	0.5417	0.2917	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B2	0.7062	0.6272	1.0000	0.0000	1.0000	0.5417	0.2708	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B3	0.8579	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B3	1.0000	1.0000	1.0000	1.0000		B3	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B4	0.7550	0.6676	1.0000	0.0000	1.0000	0.5417	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B4	1.0000	1.0000	1.0000	1.0000		B4	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B5	0.8668	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B5	1.0000	1.0000	1.0000	1.0000		B5	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	C1	0.7307	0.6672	1.0000	0.0000	1.0000	0.5833	0.2917	0.3000	1.0000	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	C2	0.9073	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D1	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		D1	1.0000	1.0000	1.0000	1.0000		D1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D2	0.9105	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		D2	1.0000	1.0000	1.0000	1.0000		D2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	E1	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		E1	1.0000	1.0000	1.0000	1.0000		E1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	E2	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		E2	1.0000	1.0000	1.0000	1.0000		E2	0.8706	0.4320	0.5912	0.5538	0.0000	0.2708	0.8083	0.0354
	E3	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		E3	0.6667	0.6667	0.6667	0.6667		E3	0.8706	0.4320	0.5912	0.5538	0.0000	0.2708	0.8083	0.0354
DRC075	BAU	0.8524	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000	DRC075	BAU	1.0000	1.0000	1.0000	1.0000	DRC075	BAU	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B1	0.7057	0.6309	1.0000	0.0000	1.0000	0.5417	0.2917	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B2	0.8554	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B3	0.8579	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B3	1.0000	1.0000	1.0000	1.0000		B3	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B4	0.8627	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B4	1.0000	1.0000	1.0000	1.0000		B4	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B5	0.8668	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B5	1.0000	1.0000	1.0000	1.0000		B5	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	C1	0.8786	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	C2	0.9073	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D1	0.7831	0.7167	1.0000	0.0000	1.0000	0.5417	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		D1	1.0000	1.0000	1.0000	1.0000		D1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D2	0.6265	0.4542	1.0000	0.0000	0.5417	0.4583	0.2708	0.0000	0.5417	1.0000	0.0000	1.0000		D2	1.0000	1.0000	1.0000	1.0000		D2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		E2	1.0000	1.0000	1.0000	1.0000		E2	0.8706	0.4320	0.5912	0.5538	0.0000	0.2708	0.8083	0.0354
	E3	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		E3	0.6667	0.6667	0.6667	0.6667		E3	0.8706	0.4320	0.5912	0.5538	0.0000	0.2708	0.8083	0.0354
DRC050	BAU	0.8524	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000	DRC050	BAU	1.0000	1.0000	1.0000	1.0000	DRC050	BAU	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B1	0.7057	0.6309	1.0000	0.0000	1.0000	0.5417	0.2917	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B2	0.8554	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B3	0.8579	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B3	1.0000	1.0000	1.0000	1.0000		B3	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B4	0.8627	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B4	1.0000	1.0000	1.0000	1.0000		B4	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.8786	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	C2	0.8577	0.8333	1.0000	0.0000	1.0000	0.8333	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D1	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		D1	1.0000	1.0000	1.0000	1.0000		D1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D2	0.9105	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		D2	1.0000	1.0000	1.0000	1.0000		D2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		E2	1.0000	1.0000	1.0000	1.0000		E2	0.8706	0.4320	0.5912	0.5538	0.0000	0.2708	0.8083	0.0354
	E3	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		E3	0.6667	0.6667	0.6667	0.6667		E3	0.8706	0.4320	0.5912	0.5538	0.0000	0.2708	0.8083	0.0354
DRC025	BAU	0.8524	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000	DRC025	BAU	1.0000	1.0000	1.0000	1.0000	DRC025	BAU	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B1	0.8544	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B2	0.7062	0.6272	1.0000	0.0000	1.0000	0.5417	0.2708	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B3	0.8579	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B3	1.0000	1.0000	1.0000	1.0000		B3	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.8786	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	C2	0.9073	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D1	0.9090	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000		D1	1.0000	1.0000	1.0000	1.0000		D1	0.8693	0.7390	0.6316	0.5769	0.0000	0.1458	0.8000	0.0438
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.8411	0.8147	1.0000	0.0000	1.0000	0.9583	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000	DRC000	BAU	1.0000	1.0000	1.0000	1.0000	DRC000	BAU	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B1	0.7057	0.6309	1.0000	0.0000	1.0000	0.5417	0.2917	0.3000	1.0000	1.0000	0.0000	1.0000		B1	1.0000	1.0000	1.0000	1.0000		B1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B2	0.8554	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B2	1.0000	1.0000	1.0000	1.0000		B2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B3	0.8579	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		B3	1.0000	1.0000	1.0000	1.0000		B3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.8786	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000		C1	1.0000	1.0000	1.0000	1.0000		C1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	C2	0.7397	0.6750	1.0000	0.0000	1.0000	0.5417	0.2917	0.0000	1.0000	1.0000	0.0000	1.0000		C2	1.0000	1.0000	1.0000	1.0000		C2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-

Appendix 33 Performance data of reliability indicators of Toyosu town

Reliability			Generation type			Generation unit								Reliability			Network unit			Reliability			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.8216	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333	DRC100	BAU	0.8636	0.8333	0.9091	0.0000	DRC100	BAU	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B1	0.8219	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B1	0.8636	0.8333	0.9091	0.0000		B1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B2	0.8221	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B2	0.8636	0.8333	0.9091	0.0000		B2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B3	0.8225	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B3	0.8636	0.8333	0.9091	0.0000		B3	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B4	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B4	0.8636	0.8333	0.9091	0.0000		B4	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B5	0.8238	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B5	0.8636	0.8333	0.9091	0.0000		B5	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	C1	0.8227	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C1	0.8636	0.8333	0.9091	0.0000		C1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	C2	0.8238	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C2	0.8636	0.8333	0.9091	0.0000		C2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D1	0.8245	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		D1	0.8636	0.8333	0.9091	0.0000		D1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D2	0.8252	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		D2	0.8636	0.8333	0.9091	0.0000		D2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	E1	0.7329	0.6872	0.8333	0.8333	0.8333	0.5000	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		E1	0.7886	0.7083	0.9091	0.0000		E1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	E2	0.7329	0.6872	0.8333	0.8333	0.8333	0.5000	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		E2	0.7886	0.7083	0.9091	0.0000		E2	0.5982	0.3949	0.7469	0.7085	0.0000	0.6814	0.7952	0.2328
	E3	0.7329	0.6872	0.8333	0.8333	0.8333	0.5000	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		E3	0.7886	0.7083	0.9091	0.0000		E3	0.5982	0.3949	0.7469	0.7085	0.0000	0.6814	0.7952	0.2328
DRC075	BAU	0.8216	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333	DRC075	BAU	0.8636	0.8333	0.9091	0.0000	DRC075	BAU	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B1	0.8219	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B1	0.8636	0.8333	0.9091	0.0000		B1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B2	0.8221	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B2	0.8636	0.8333	0.9091	0.0000		B2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B3	0.8225	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B3	0.8636	0.8333	0.9091	0.0000		B3	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B4	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B4	0.8636	0.8333	0.9091	0.0000		B4	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B5	0.8238	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B5	0.8636	0.8333	0.9091	0.0000		B5	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	C1	0.8227	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C1	0.8636	0.8333	0.9091	0.0000		C1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	C2	0.8238	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C2	0.8636	0.8333	0.9091	0.0000		C2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D1	0.8245	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		D1	0.8636	0.8333	0.9091	0.0000		D1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D2	0.8252	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		D2	0.8636	0.8333	0.9091	0.0000		D2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.7329	0.6872	0.8333	0.8333	0.8333	0.5000	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		E2	0.7886	0.7083	0.9091	0.0000		E2	0.5982	0.3949	0.7469	0.7085	0.0000	0.6814	0.7952	0.2328
	E3	0.7329	0.6872	0.8333	0.8333	0.8333	0.5000	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		E3	0.7886	0.7083	0.9091	0.0000		E3	0.5982	0.3949	0.7469	0.7085	0.0000	0.6814	0.7952	0.2328
DRC050	BAU	0.8216	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333	DRC050	BAU	0.8636	0.8333	0.9091	0.0000	DRC050	BAU	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B1	0.8219	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B1	0.8636	0.8333	0.9091	0.0000		B1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B2	0.8221	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B2	0.8636	0.8333	0.9091	0.0000		B2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B3	0.8225	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B3	0.8636	0.8333	0.9091	0.0000		B3	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B4	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B4	0.8636	0.8333	0.9091	0.0000		B4	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.8227	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C1	0.8636	0.8333	0.9091	0.0000		C1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	C2	0.8238	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C2	0.8636	0.8333	0.9091	0.0000		C2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D1	0.8245	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		D1	0.8636	0.8333	0.9091	0.0000		D1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D2	0.8252	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		D2	0.8636	0.8333	0.9091	0.0000		D2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.7329	0.6872	0.8333	0.8333	0.8333	0.5000	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		E2	0.7886	0.7083	0.9091	0.0000		E2	0.5982	0.3949	0.7469	0.7085	0.0000	0.6814	0.7952	0.2328
	E3	0.7329	0.6872	0.8333	0.8333	0.8333	0.5000	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		E3	0.7886	0.7083	0.9091	0.0000		E3	0.5982	0.3949	0.7469	0.7085	0.0000	0.6814	0.7952	0.2328
DRC025	BAU	0.8216	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333	DRC025	BAU	0.8636	0.8333	0.9091	0.0000	DRC025	BAU	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B1	0.8219	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B1	0.8636	0.8333	0.9091	0.0000		B1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B2	0.8221	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B2	0.8636	0.8333	0.9091	0.0000		B2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B3	0.8225	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B3	0.8636	0.8333	0.9091	0.0000		B3	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.8227	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C1	0.8636	0.8333	0.9091	0.0000		C1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	C2	0.8238	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C2	0.8636	0.8333	0.9091	0.0000		C2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D1	0.8245	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		D1	0.8636	0.8333	0.9091	0.0000		D1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.8216	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333	DRC000	BAU	0.8636	0.8333	0.9091	0.0000	DRC000	BAU	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B1	0.8219	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B1	0.8636	0.8333	0.9091	0.0000		B1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B2	0.8221	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B2	0.8636	0.8333	0.9091	0.0000		B2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B3	0.8225	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		B3	0.8636	0.8333	0.9091	0.0000		B3	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.8227	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C1	0.8636	0.8333	0.9091	0.0000		C1	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	C2	0.8238	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333		C2	0.8636	0.8333	0.9091	0.0000		C2	0.7401	0.7560	0.7794	0.7172	0.0000	0.2975	0.7903	0.2394
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-

Appendix 34 Performance data of vulnerability indicators of Toyosu town

Vulnerability			Generation type			Generation unit								**Vulnerability**			Network unit			**Vulnerability**			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.4267	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC100	BAU	0.3660	0.4300	0.2700	0.0000	DRC100	BAU	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B1	0.4260	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B2	0.4256	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B3	0.4248	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B4	0.4231	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B4	0.3660	0.4300	0.2700	0.0000		B4	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B5	0.4217	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B5	0.3660	0.4300	0.2700	0.0000		B5	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	C1	0.4317	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	C2	0.4373	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D1	0.4344	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D2	0.4319	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D2	0.3660	0.4300	0.2700	0.0000		D2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	E1	0.5470	0.6140	0.4300	0.0100	0.4300	0.8400	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		E1	0.4583	0.5838	0.2700	0.0000		E1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	E2	0.5470	0.6140	0.4300	0.0100	0.4300	0.8400	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		E2	0.4583	0.5838	0.2700	0.0000		E2	0.6951	0.8809	0.5798	0.6261	0.0000	0.3638	0.5613	0.2856
	E3	0.5470	0.6140	0.4300	0.0100	0.4300	0.8400	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		E3	0.4583	0.5838	0.2700	0.0000		E3	0.6951	0.8809	0.5798	0.6261	0.0000	0.3638	0.5613	0.2856
DRC075	BAU	0.4267	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC075	BAU	0.3660	0.4300	0.2700	0.0000	DRC075	BAU	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B1	0.4260	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B2	0.4256	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B3	0.4248	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B4	0.4231	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B4	0.3660	0.4300	0.2700	0.0000		B4	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B5	0.4217	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B5	0.3660	0.4300	0.2700	0.0000		B5	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	C1	0.4317	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	C2	0.4373	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D1	0.4344	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D2	0.4319	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D2	0.3660	0.4300	0.2700	0.0000		D2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.5470	0.6140	0.4300	0.0100	0.4300	0.8400	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		E2	0.4583	0.5838	0.2700	0.0000		E2	0.6951	0.8809	0.5798	0.6261	0.0000	0.3638	0.5613	0.2856
	E3	0.5470	0.6140	0.4300	0.0100	0.4300	0.8400	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		E3	0.4583	0.5838	0.2700	0.0000		E3	0.6951	0.8809	0.5798	0.6261	0.0000	0.3638	0.5613	0.2856
DRC050	BAU	0.4267	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC050	BAU	0.3660	0.4300	0.2700	0.0000	DRC050	BAU	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B1	0.4260	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B2	0.4256	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B3	0.4248	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B4	0.4231	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B4	0.3660	0.4300	0.2700	0.0000		B4	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.4317	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	C2	0.4373	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D1	0.4344	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D2	0.4319	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D2	0.3660	0.4300	0.2700	0.0000		D2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.5470	0.6140	0.4300	0.0100	0.4300	0.8400	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		E2	0.4583	0.5838	0.2700	0.0000		E2	0.6951	0.8809	0.5798	0.6261	0.0000	0.3638	0.5613	0.2856
	E3	0.5470	0.6140	0.4300	0.0100	0.4300	0.8400	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		E3	0.4583	0.5838	0.2700	0.0000		E3	0.6951	0.8809	0.5798	0.6261	0.0000	0.3638	0.5613	0.2856
DRC025	BAU	0.4267	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC025	BAU	0.3660	0.4300	0.2700	0.0000	DRC025	BAU	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B1	0.4260	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B2	0.4256	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B3	0.4248	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.4317	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	C2	0.4373	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D1	0.4344	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-
DRC000	BAU	0.4267	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC000	BAU	0.3660	0.4300	0.2700	0.0000	DRC000	BAU	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B1	0.4260	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B2	0.4256	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B3	0.4248	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.4317	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	C2	0.4373	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5719	0.5811	0.5532	0.6105	0.0000	0.5588	0.5420	0.2888
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	-	-	-	-	-	-	-	-	-	-	-	-		E3	-	-	-	-		E3	-	-	-	-	-	-	-	-

Appendix 35 Status of power balance of Kitakoujiya town in various disturbance scenarios

Power balance	DRC100	DRC075	DRC050	DRC025	DRC000
BAU	OK	OK	OK	OK	OK
B1	OK	OK	OK	OK	OK
B2	OK	OK	OK	OK	OK
B3	OK	OK	OK	OK	OK
B4	OK	OK	OK	FAIL	FAIL
B5	OK	FAIL	FAIL	FAIL	FAIL
C1	OK	OK	OK	OK	OK
C2	OK	OK	OK	OK	OK
D1	OK	OK	OK	OK	FAIL
D2	OK	OK	FAIL	FAIL	FAIL
E1	OK	-	-	-	-
E2	OK	OK	OK	OK	FAIL
E3	-	-	-	-	-

Appendix 36 Performance data of functionality indicators of Kitakoujiya town

Demand users' convenience			Component unit							Cost of electric energy (yen/kWh)		
		System	Residential	Office	Commercial	Hotel	Factory	School	Hospital			System
DRC100	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC100	BAU	8.5218
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	9.0522
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.4353
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.5448
	B4	0.9452	0.9420	0.9333	0.9313	0.0000	0.9581	0.8667	0.9937		B4	14.1369
	B5	0.8648	0.8640	0.8114	0.8441	0.0000	0.8489	0.7393	0.9925		B5	19.7390
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.9785
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.5544
	D1	0.9895	0.9887	0.9882	0.9864	0.0000	0.9899	0.9789	0.9978		D1	12.3597
	D2	0.8848	0.8853	0.8399	0.8633	0.0000	0.8797	0.7692	0.9927		D2	18.0957
	E1	0.9895	0.9887	0.9882	0.9864	0.0000	0.9899	0.9789	0.9978		E1	12.3597
	E2	0.9885	0.9946	0.9851	0.9799	0.0000	0.9871	0.9782	1.0000		E2	12.3597
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000
DRC075	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC075	BAU	8.5218
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	9.0522
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.4353
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.5448
	B4	0.9508	0.9478	0.9384	0.9374	0.0000	0.9599	0.8869	0.9950		B4	14.1369
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.9785
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.5544
	D1	0.9912	0.9907	0.9903	0.9889	0.0000	0.9902	0.9838	0.9983		D1	12.3597
	D2	0.8989	0.9018	0.8612	0.8822	0.0000	0.8851	0.8043	0.9939		D2	18.0957
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	0.9906	0.9957	0.9880	0.9839	0.0000	0.9881	0.9834	1.0000		E2	12.3597
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000
DRC050	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC050	BAU	8.5218
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	9.0522
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.4353
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.5448
	B4	0.9549	0.9528	0.9406	0.9436	0.0000	0.9574	0.9067	0.9962		B4	14.1369
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.9785
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.5544
	D1	0.9934	0.9932	0.9930	0.9921	0.0000	0.9912	0.9890	0.9989		D1	12.3597
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	0.9934	0.9971	0.9918	0.9891	0.0000	0.9907	0.9890	1.0000		E2	12.3597
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000
DRC025	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC025	BAU	8.5218
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	9.0522
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.4353
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.5448
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.9785
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.5544
	D1	0.9934	0.9931	0.9930	0.9920	0.0000	0.9916	0.9883	0.9988		D1	12.3597
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	0.9965	0.9985	0.9958	0.9944	0.0000	0.9946	0.9944	1.0000		E2	12.3597
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000
DRC000	BAU	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	DRC000	BAU	8.5218
	B1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B1	9.0522
	B2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B2	9.4353
	B3	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		B3	10.5448
	B4	-	-	-	-	-	-	-	-		B4	-
	B5	-	-	-	-	-	-	-	-		B5	-
	C1	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C1	8.9785
	C2	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000		C2	9.5544
	D1	-	-	-	-	-	-	-	-		D1	-
	D2	-	-	-	-	-	-	-	-		D2	-
	E1	-	-	-	-	-	-	-	-		E1	-
	E2	-	-	-	-	-	-	-	-		E2	-
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000

Appendix 37 Performance data of redundancy indicators of Kitakoujiya town

Redundancy			Generation type			Generation unit								Redundancy			Network unit			Redundancy			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.5729	0.5054	0.9994	0.0088	0.8503	0.4771	0.3147	0.0322	0.6600	1.0000	0.0088	0.9992	DRC100	BAU	0.9831	0.9765	0.9931	0.0000	DRC100	BAU	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B1	0.5427	0.4561	0.9957	0.0088	0.7713	0.4404	0.2982	0.0000	0.5659	1.0000	0.0088	0.9945		B1	0.9833	0.9768	0.9931	0.0000		B1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B2	0.5273	0.4301	0.9916	0.0088	0.7170	0.4197	0.2790	0.0000	0.5443	1.0000	0.0088	0.9894		B2	0.9835	0.9772	0.9931	0.0000		B2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B3	0.4972	0.3792	0.9724	0.0088	0.6220	0.3851	0.2328	0.0000	0.4744	0.9971	0.0088	0.9660		B3	0.9843	0.9784	0.9931	0.0000		B3	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B4	0.4269	0.2747	0.8887	0.0088	0.4609	0.3056	0.1389	0.0000	0.2881	0.9639	0.0088	0.8691		B4	0.9847	0.9789	0.9934	0.0000		B4	0.9054	0.6838	0.7244	0.6285	0.0000	0.5124	0.7478	0.1399
	B5	0.4185	0.2216	0.9027	0.0088	0.3166	0.3000	0.0556	0.0000	0.2667	0.9638	0.0088	0.8868		B5	0.9863	0.9810	0.9941	0.0000		B5	0.7673	0.5789	0.6110	0.5372	0.0000	0.4246	0.6472	0.1359
	C1	0.5554	0.4771	0.9976	0.0088	0.8033	0.4380	0.2059	0.0000	0.5875	1.0000	0.0088	0.9970		C1	0.9832	0.9766	0.9931	0.0000		C1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	C2	0.5372	0.4469	0.9945	0.0088	0.7394	0.3940	0.0946	0.0000	0.5491	1.0000	0.0088	0.9931		C2	0.9832	0.9766	0.9931	0.0000		C2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	D1	0.4465	0.3094	0.9127	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8931		D1	0.9844	0.9785	0.9932	0.0000		D1	0.9822	0.7497	0.7785	0.6738	0.0000	0.5356	0.8247	0.1570
	D2	0.4058	0.2348	0.8575	0.0088	0.3457	0.2639	0.0000	0.0000	0.2778	0.9638	0.0088	0.8298		D2	0.9857	0.9802	0.9939	0.0000		D2	0.8025	0.6019	0.6420	0.5703	0.0000	0.4551	0.6796	0.1365
	E1	0.4465	0.3094	0.9127	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8931		E1	0.9844	0.9785	0.9932	0.0000		E1	0.9822	0.7497	0.7785	0.6738	0.0000	0.5356	0.8247	0.1570
	E2	0.4464	0.3094	0.9126	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8930		E2	0.9843	0.9785	0.9932	0.0000		E2	0.9807	0.3281	0.7232	0.7474	0.0000	0.5343	0.8138	0.2292
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	0.5729	0.5054	0.9994	0.0088	0.8503	0.4770	0.3149	0.0320	0.6600	1.0000	0.0088	0.9992	DRC075	BAU	0.9831	0.9765	0.9931	0.0000	DRC075	BAU	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B1	0.5427	0.4561	0.9957	0.0088	0.7713	0.4404	0.2982	0.0000	0.5659	1.0000	0.0088	0.9945		B1	0.9833	0.9768	0.9931	0.0000		B1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B2	0.5273	0.4301	0.9916	0.0088	0.7170	0.4197	0.2790	0.0000	0.5443	1.0000	0.0088	0.9894		B2	0.9835	0.9772	0.9931	0.0000		B2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B3	0.4972	0.3792	0.9724	0.0088	0.6220	0.3851	0.2328	0.0000	0.4744	0.9971	0.0088	0.9660		B3	0.9843	0.9784	0.9931	0.0000		B3	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B4	0.4257	0.2747	0.8847	0.0088	0.4609	0.3056	0.1389	0.0000	0.2881	0.9640	0.0088	0.8640		B4	0.9847	0.9790	0.9934	0.0000		B4	0.8864	0.6680	0.7104	0.6169	0.0000	0.5043	0.7371	0.1387
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.5554	0.4771	0.9976	0.0088	0.8033	0.4380	0.2059	0.0000	0.5875	1.0000	0.0088	0.9970		C1	0.9832	0.9766	0.9931	0.0000		C1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	C2	0.5372	0.4469	0.9945	0.0088	0.7394	0.3940	0.0946	0.0000	0.5491	1.0000	0.0088	0.9931		C2	0.9834	0.9769	0.9931	0.0000		C2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	D1	0.4464	0.3094	0.9127	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8931		D1	0.9844	0.9785	0.9932	0.0000		D1	0.9802	0.7484	0.7774	0.6731	0.0000	0.5338	0.8243	0.1569
	D2	0.4061	0.2348	0.8587	0.0088	0.3457	0.2639	0.0000	0.0000	0.2778	0.9638	0.0088	0.8313		D2	0.9857	0.9803	0.9938	0.0000		D2	0.7708	0.5792	0.6175	0.5538	0.0000	0.4317	0.6557	0.1332
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4465	0.3094	0.9129	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8934		E2	0.9844	0.9785	0.9932	0.0000		E2	0.9794	0.3278	0.7222	0.7466	0.0000	0.5326	0.8135	0.2292
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	0.5729	0.5054	0.9994	0.0088	0.8503	0.4766	0.3166	0.0307	0.6600	1.0000	0.0088	0.9992	DRC050	BAU	0.9831	0.9765	0.9931	0.0000	DRC050	BAU	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B1	0.5427	0.4561	0.9957	0.0088	0.7713	0.4404	0.2982	0.0000	0.5659	1.0000	0.0088	0.9945		B1	0.9833	0.9768	0.9931	0.0000		B1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B2	0.5273	0.4301	0.9916	0.0088	0.7170	0.4197	0.2790	0.0000	0.5443	1.0000	0.0088	0.9894		B2	0.9835	0.9772	0.9931	0.0000		B2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B3	0.4972	0.3792	0.9724	0.0088	0.6220	0.3851	0.2328	0.0000	0.4744	0.9971	0.0088	0.9660		B3	0.9843	0.9784	0.9931	0.0000		B3	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B4	0.4264	0.2747	0.8869	0.0088	0.4609	0.3056	0.1389	0.0000	0.2881	0.9640	0.0088	0.8667		B4	0.9847	0.9790	0.9934	0.0000		B4	0.8456	0.6362	0.6783	0.5948	0.0000	0.4822	0.7127	0.1346
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.5554	0.4771	0.9976	0.0088	0.8033	0.4380	0.2059	0.0000	0.5875	1.0000	0.0088	0.9970		C1	0.9832	0.9766	0.9931	0.0000		C1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	C2	0.5372	0.4469	0.9945	0.0088	0.7394	0.3940	0.0946	0.0000	0.5491	1.0000	0.0088	0.9931		C2	0.9834	0.9769	0.9931	0.0000		C2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	D1	0.4465	0.3094	0.9129	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8933		D1	0.9844	0.9785	0.9932	0.0000		D1	0.9780	0.7471	0.7764	0.6725	0.0000	0.5311	0.8240	0.1570
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4465	0.3094	0.9127	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8932		E2	0.9844	0.9785	0.9931	0.0000		E2	0.9789	0.3278	0.7219	0.7465	0.0000	0.5313	0.8135	0.2292
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	0.5729	0.5054	0.9994	0.0088	0.8503	0.4772	0.3142	0.0326	0.6600	1.0000	0.0088	0.9992	DRC025	BAU	0.9831	0.9765	0.9931	0.0000	DRC025	BAU	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B1	0.5427	0.4561	0.9957	0.0088	0.7713	0.4404	0.2982	0.0000	0.5659	1.0000	0.0088	0.9945		B1	0.9833	0.9768	0.9931	0.0000		B1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B2	0.5273	0.4301	0.9916	0.0088	0.7170	0.4197	0.2790	0.0000	0.5443	1.0000	0.0088	0.9894		B2	0.9835	0.9772	0.9931	0.0000		B2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B3	0.4972	0.3792	0.9724	0.0088	0.6220	0.3851	0.2328	0.0000	0.4744	0.9971	0.0088	0.9660		B3	0.9843	0.9784	0.9931	0.0000		B3	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.5554	0.4771	0.9976	0.0088	0.8033	0.4380	0.2059	0.0000	0.5875	1.0000	0.0088	0.9970		C1	0.9832	0.9766	0.9931	0.0000		C1	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	C2	0.5372	0.4469	0.9945	0.0088	0.7394	0.3940	0.0946	0.0000	0.5491	1.0000	0.0088	0.9931		C2	0.9834	0.9769	0.9931	0.0000		C2	0.9987	0.7628	0.7895	0.6833	0.0000	0.5431	0.8438	0.1667
	D1	0.4465	0.3094	0.9126	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8931		D1	0.9844	0.9785	0.9932	0.0000		D1	0.9570	0.7308	0.7632	0.6611	0.0000	0.5201	0.8021	0.1458
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4465	0.3094	0.9125	0.0088	0.5387	0.3111	0.0000	0.0000	0.3096	0.9876	0.0088	0.8929		E2	0.9844	0.9786	0.9931	0.0000		E2	0.9781	0.3276	0.7216	0.7462	0.0000	0.5298	0.8132	0.2292
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	0.5729	0.5054	0.9994	0.0088	0.8503	0.4772	0.3142	0.0325	0.6600	1.0000	0.0088	0.9992	DRC000	BAU	0.9831	0.9765	0.9931	0.0000	DRC000	BAU	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B1	0.5427	0.4561	0.9957	0.0088	0.7713	0.4404	0.2982	0.0000	0.5659	1.0000	0.0088	0.9945		B1	0.9833	0.9768	0.9931	0.0000		B1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B2	0.5273	0.4301	0.9916	0.0088	0.7170	0.4197	0.2790	0.0000	0.5443	1.0000	0.0088	0.9894		B2	0.9835	0.9772	0.9931	0.0000		B2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B3	0.4972	0.3792	0.9724	0.0088	0.6220	0.3851	0.2328	0.0000	0.4744	0.9971	0.0088	0.9660		B3	0.9843	0.9784	0.9931	0.0000		B3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.5554	0.4771	0.9976	0.0088	0.8033	0.4380	0.2059	0.0000	0.5875	1.0000	0.0088	0.9970		C1	0.9832	0.9766	0.9931	0.0000		C1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	C2	0.5372	0.4469	0.9945	0.0088	0.7394	0.3940	0.0946	0.0000	0.5491	1.0000	0.0088	0.9931		C2	0.9834	0.9769	0.9931	0.0000		C2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix 38 Performance data of adaptability indicators of Kitakoujiya town

Adaptability			Generation type			Generation unit							
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage
DRC100	BAU	0.7647	0.7706	1.0000	0.0000	1.0000	0.8333	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B1	0.8057	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B2	0.8047	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B3	0.8025	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B4	0.5076	0.3549	1.0000	0.0000	0.6250	0.3333	0.1667	0.1000	0.4167	1.0000	0.0000	1.0000
	B5	0.7949	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	C1	0.7297	0.7219	1.0000	0.0000	1.0000	0.6250	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	C2	0.6555	0.6153	1.0000	0.0000	0.9167	0.5833	0.2708	0.0000	0.6250	1.0000	0.0000	1.0000
	D1	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	D2	0.5417	0.3931	1.0000	0.0000	0.5000	0.3750	0.1875	0.0000	0.5417	1.0000	0.0000	1.0000
	E1	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	E2	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	0.6529	0.6164	1.0000	0.0000	0.9583	0.6250	0.3125	0.1875	0.7917	1.0000	0.0000	1.0000
	B1	0.8057	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B2	0.8047	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B3	0.8025	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B4	0.7984	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8300	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	C2	0.6555	0.6153	1.0000	0.0000	0.9167	0.5833	0.2708	0.0000	0.6250	1.0000	0.0000	1.0000
	D1	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	D2	0.8371	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	0.6529	0.6164	1.0000	0.0000	0.9583	0.6250	0.3125	0.1875	0.7917	1.0000	0.0000	1.0000
	B1	0.8057	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B2	0.8047	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B3	0.8025	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B4	0.7984	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.7632	0.7688	1.0000	0.0000	1.0000	0.7500	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	C2	0.7498	0.7500	1.0000	0.0000	1.0000	0.6250	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	D1	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	0.6529	0.6164	1.0000	0.0000	0.9583	0.6250	0.3125	0.1875	0.7917	1.0000	0.0000	1.0000
	B1	0.7708	0.7799	1.0000	0.0000	1.0000	0.9167	0.4583	0.2750	0.9167	1.0000	0.0000	1.0000
	B2	0.8047	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B3	0.8025	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8300	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	C2	0.6555	0.6153	1.0000	0.0000	0.9167	0.5833	0.2708	0.0000	0.6250	1.0000	0.0000	1.0000
	D1	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	0.8451	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	0.7967	0.8147	1.0000	0.0000	1.0000	0.9583	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B1	0.8057	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B2	0.7466	0.7453	1.0000	0.0000	0.9583	0.8750	0.4375	0.2625	0.8750	1.0000	0.0000	1.0000
	B3	0.8025	0.8294	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8300	0.8625	1.0000	0.0000	1.0000	1.0000	0.5000	0.3000	1.0000	1.0000	0.0000	1.0000
	C2	0.8547	0.9000	1.0000	0.0000	1.0000	1.0000	0.5000	0.0000	1.0000	1.0000	0.0000	1.0000
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Adaptability			Network unit		
		System	Feeder	Primary	Bypass
DRC100	BAU	1.0000	1.0000	1.0000	1.0000
	B1	1.0000	1.0000	1.0000	1.0000
	B2	1.0000	1.0000	1.0000	1.0000
	B3	1.0000	1.0000	1.0000	1.0000
	B4	1.0000	1.0000	1.0000	1.0000
	B5	1.0000	1.0000	1.0000	1.0000
	C1	1.0000	1.0000	1.0000	1.0000
	C2	1.0000	1.0000	1.0000	1.0000
	D1	1.0000	1.0000	1.0000	1.0000
	D2	1.0000	1.0000	1.0000	1.0000
	E1	1.0000	1.0000	1.0000	1.0000
	E2	1.0000	1.0000	1.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	1.0000	1.0000	1.0000	1.0000
	B1	1.0000	1.0000	1.0000	1.0000
	B2	1.0000	1.0000	1.0000	1.0000
	B3	1.0000	1.0000	1.0000	1.0000
	B4	1.0000	1.0000	1.0000	1.0000
	B5	-	-	-	-
	C1	1.0000	1.0000	1.0000	1.0000
	C2	1.0000	1.0000	1.0000	1.0000
	D1	1.0000	1.0000	1.0000	1.0000
	D2	1.0000	1.0000	1.0000	1.0000
	E1	-	-	-	-
	E2	1.0000	1.0000	1.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	1.0000	1.0000	1.0000	1.0000
	B1	1.0000	1.0000	1.0000	1.0000
	B2	1.0000	1.0000	1.0000	1.0000
	B3	1.0000	1.0000	1.0000	1.0000
	B4	1.0000	1.0000	1.0000	1.0000
	B5	-	-	-	-
	C1	1.0000	1.0000	1.0000	1.0000
	C2	1.0000	1.0000	1.0000	1.0000
	D1	1.0000	1.0000	1.0000	1.0000
	D2	-	-	-	-
	E1	-	-	-	-
	E2	1.0000	1.0000	1.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	1.0000	1.0000	1.0000	1.0000
	B1	1.0000	1.0000	1.0000	1.0000
	B2	1.0000	1.0000	1.0000	1.0000
	B3	1.0000	1.0000	1.0000	1.0000
	B4	-	-	-	-
	B5	-	-	-	-
	C1	1.0000	1.0000	1.0000	1.0000
	C2	1.0000	1.0000	1.0000	1.0000
	D1	1.0000	1.0000	1.0000	1.0000
	D2	-	-	-	-
	E1	-	-	-	-
	E2	1.0000	1.0000	1.0000	1.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	1.0000	1.0000	1.0000	1.0000
	B1	1.0000	1.0000	1.0000	1.0000
	B2	1.0000	1.0000	1.0000	1.0000
	B3	1.0000	1.0000	1.0000	1.0000
	B4	-	-	-	-
	B5	-	-	-	-
	C1	1.0000	1.0000	1.0000	1.0000
	C2	1.0000	1.0000	1.0000	1.0000
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000

Adaptability			Consumption unit						
		System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B3	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B4	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B5	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	C1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	C2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	D1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	D2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	E1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	E2	0.8921	0.3344	0.5895	0.6089	0.0000	0.2716	0.8333	0.0458
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B3	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B4	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B5	-	-	-	-	-	-	-	-
	C1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	C2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	D1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	D2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	E1	-	-	-	-	-	-	-	-
	E2	0.8921	0.3344	0.5895	0.6089	0.0000	0.2716	0.8333	0.0458
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B3	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B4	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B5	-	-	-	-	-	-	-	-
	C1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	C2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	D1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	0.8921	0.3344	0.5895	0.6089	0.0000	0.2716	0.8333	0.0458
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B3	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	C2	0.8921	0.7628	0.6316	0.5467	0.0000	0.2716	0.8438	0.0333
	D1	0.8921	0.7532	0.6263	0.5444	0.0000	0.2622	0.8438	0.0333
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	0.8921	0.3344	0.5895	0.6089	0.0000	0.2716	0.8333	0.0458
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	C2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix 39 Performance data of reliability indicators of Kitakoujiya town

Reliability			Generation type			Generation unit							
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage
DRC100	BAU	0.8223	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8226	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8228	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B4	0.8240	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B5	0.8247	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C1	0.8233	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8244	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	0.8252	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D2	0.8259	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	E1	0.7948	0.8205	0.8333	0.5000	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.5000	0.8333
	E2	0.7948	0.8205	0.8333	0.5000	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.5000	0.8333
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	0.8223	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8226	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8228	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B4	0.8240	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8233	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8244	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	0.8252	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D2	0.8259	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	0.7948	0.8205	0.8333	0.5000	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.5000	0.8333
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	0.8223	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8226	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8228	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B4	0.8240	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8233	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8244	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	0.8252	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	0.7948	0.8205	0.8333	0.5000	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.5000	0.8333
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	0.8223	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8226	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8228	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8233	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8244	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	0.8252	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	0.7948	0.8205	0.8333	0.5000	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.5000	0.8333
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	0.8223	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B1	0.8226	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B2	0.8228	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B3	0.8232	0.8181	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	B4	-	-	-	-	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-
	C1	0.8233	0.8192	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	C2	0.8244	0.8205	0.8333	0.8333	0.8333	0.8333	0.7692	0.8000	0.8333	0.8333	0.8333	0.8333
	D1	-	-	-	-	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Reliability			Network unit		
		System	Feeder	Primary	Bypass
DRC100	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	0.8636	0.8333	0.9091	0.0000
	B4	0.8636	0.8333	0.9091	0.0000
	B5	0.8636	0.8333	0.9091	0.0000
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	0.8636	0.8333	0.9091	0.0000
	D2	0.8636	0.8333	0.9091	0.0000
	E1	0.7750	0.8333	0.6875	0.0000
	E2	0.7750	0.8333	0.6875	0.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	0.8636	0.8333	0.9091	0.0000
	B4	0.8636	0.8333	0.9091	0.0000
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	0.8636	0.8333	0.9091	0.0000
	D2	0.8636	0.8333	0.9091	0.0000
	E1	-	-	-	-
	E2	0.7750	0.8333	0.6875	0.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	0.8636	0.8333	0.9091	0.0000
	B4	0.8636	0.8333	0.9091	0.0000
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	0.8636	0.8333	0.9091	0.0000
	D2	-	-	-	-
	E1	-	-	-	-
	E2	0.7750	0.8333	0.6875	0.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	0.8636	0.8333	0.9091	0.0000
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	0.8636	0.8333	0.9091	0.0000
	D2	-	-	-	-
	E1	-	-	-	-
	E2	0.7750	0.8333	0.6875	0.0000
	E3	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	0.8636	0.8333	0.9091	0.0000
	B1	0.8636	0.8333	0.9091	0.0000
	B2	0.8636	0.8333	0.9091	0.0000
	B3	0.8636	0.8333	0.9091	0.0000
	B4	-	-	-	-
	B5	-	-	-	-
	C1	0.8636	0.8333	0.9091	0.0000
	C2	0.8636	0.8333	0.9091	0.0000
	D1	-	-	-	-
	D2	-	-	-	-
	E1	-	-	-	-
	E2	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000

Reliability			Consumption unit						
		System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B3	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B4	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B5	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	C1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	C2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	E1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	E2	0.4118	0.3386	0.7655	0.7257	0.0000	0.5318	0.7929	0.2351
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B3	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B4	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B5	-	-	-	-	-	-	-	-
	C1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	C2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	E1	-	-	-	-	-	-	-	-
	E2	0.4118	0.3386	0.7655	0.7257	0.0000	0.5318	0.7929	0.2351
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B3	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B4	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B5	-	-	-	-	-	-	-	-
	C1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	C2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	0.4118	0.3386	0.7655	0.7257	0.0000	0.5318	0.7929	0.2351
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B3	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	C2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	0.4118	0.3386	0.7655	0.7257	0.0000	0.5318	0.7929	0.2351
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B3	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-
	C1	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	C2	0.7150	0.7547	0.7704	0.6856	0.0000	0.5445	0.7958	0.2096
	D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix 40 Performance data of vulnerability indicators of Kitakoujiya town

Vulnerability			Generation type			Generation unit								Vulnerability			Network unit			Vulnerability			Consumption unit						
		System	Stable	Storage	Intermittent	Oil	LNG+LPG	Coal	Nuclear	Hydroelectric	PS Hydroelectric	PV	Storage			System	Feeder	Primary	Bypass			System	Residential	Office	Commercial	Hotel	Factory	School	Hospital
DRC100	BAU	0.4045	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC100	BAU	0.3660	0.4300	0.2700	0.0000	DRC100	BAU	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B1	0.4021	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B2	0.4008	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B3	0.3978	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B4	0.3921	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B4	0.3660	0.4300	0.2700	0.0000		B4	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B5	0.3873	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B5	0.3660	0.4300	0.2700	0.0000		B5	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	C1	0.4082	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	C2	0.4124	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D1	0.4044	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D2	0.3977	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D2	0.3660	0.4300	0.2700	0.0000		D2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	E1	0.4135	0.4500	0.4300	0.1100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.1100	0.4300		E1	0.4678	0.4300	0.5246	0.0000		E1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	E2	0.4135	0.4500	0.4300	0.1100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.1100	0.4300		E2	0.4678	0.4300	0.5246	0.0000		E2	0.7933	0.9157	0.5633	0.5997	0.0000	0.4276	0.5525	0.2888
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC075	BAU	0.4045	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC075	BAU	0.3660	0.4300	0.2700	0.0000	DRC075	BAU	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B1	0.4021	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B2	0.4008	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B3	0.3978	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B4	0.3921	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B4	0.3660	0.4300	0.2700	0.0000		B4	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.4082	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	C2	0.4124	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D1	0.4044	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D2	0.3977	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D2	0.3660	0.4300	0.2700	0.0000		D2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4135	0.4500	0.4300	0.1100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.1100	0.4300		E2	0.4678	0.4300	0.5246	0.0000		E2	0.7933	0.9157	0.5633	0.5997	0.0000	0.4276	0.5525	0.2888
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC050	BAU	0.4045	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC050	BAU	0.3660	0.4300	0.2700	0.0000	DRC050	BAU	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B1	0.4021	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B2	0.4008	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B3	0.3978	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B4	0.3921	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B4	0.3660	0.4300	0.2700	0.0000		B4	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.4082	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	C2	0.4124	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D1	0.4044	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4135	0.4500	0.4300	0.1100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.1100	0.4300		E2	0.4678	0.4300	0.5246	0.0000		E2	0.7933	0.9157	0.5633	0.5997	0.0000	0.4276	0.5525	0.2888
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC025	BAU	0.4045	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC025	BAU	0.3660	0.4300	0.2700	0.0000	DRC025	BAU	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B1	0.4021	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B2	0.4008	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B3	0.3978	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.4082	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	C2	0.4124	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D1	0.4044	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		D1	0.3660	0.4300	0.2700	0.0000		D1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	0.4135	0.4500	0.4300	0.1100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.1100	0.4300		E2	0.4678	0.4300	0.5246	0.0000		E2	0.7933	0.9157	0.5633	0.5997	0.0000	0.4276	0.5525	0.2888
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DRC000	BAU	0.4045	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300	DRC000	BAU	0.3660	0.4300	0.2700	0.0000	DRC000	BAU	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B1	0.4021	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B1	0.3660	0.4300	0.2700	0.0000		B1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B2	0.4008	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B2	0.3660	0.4300	0.2700	0.0000		B2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B3	0.3978	0.4347	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		B3	0.3660	0.4300	0.2700	0.0000		B3	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	B4	-	-	-	-	-	-	-	-	-	-	-	-		B4	-	-	-	-		B4	-	-	-	-	-	-	-	-
	B5	-	-	-	-	-	-	-	-	-	-	-	-		B5	-	-	-	-		B5	-	-	-	-	-	-	-	-
	C1	0.4082	0.4419	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C1	0.3660	0.4300	0.2700	0.0000		C1	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	C2	0.4124	0.4500	0.4300	0.0100	0.4300	0.4300	0.5300	0.3200	0.4300	0.4300	0.0100	0.4300		C2	0.3660	0.4300	0.2700	0.0000		C2	0.5516	0.5836	0.5730	0.6533	0.0000	0.4151	0.5306	0.3294
	D1	-	-	-	-	-	-	-	-	-	-	-	-		D1	-	-	-	-		D1	-	-	-	-	-	-	-	-
	D2	-	-	-	-	-	-	-	-	-	-	-	-		D2	-	-	-	-		D2	-	-	-	-	-	-	-	-
	E1	-	-	-	-	-	-	-	-	-	-	-	-		E1	-	-	-	-		E1	-	-	-	-	-	-	-	-
	E2	-	-	-	-	-	-	-	-	-	-	-	-		E2	-	-	-	-		E2	-	-	-	-	-	-	-	-
	E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000		E3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix 41 Weightage assigned for each power component for Umegaoka town

Generation category	Generation type	Max power generation (kW)	Weightage by considering individual category	Weightage by considering all categories
Stable	Oil	5400	0.24	0.64
	LNG+LPG	8100	0.35	
	Coal	4050	0.18	
	Nuclear	2700	0.12	
	Hydroelectric	2700	0.12	
Storage-based	PS Hydroelectric	1350	0.18	0.21
	Storage 1	3187	0.42	
	Storage 2	2227	0.29	
	Storage 3	903	0.12	
Intermittent	PV1	2150	0.41	0.14
	PV2	2091	0.40	
	PV3	944	0.18	

Network type	Weightage
Feeder	0.6
Primary	0.4

Building type	Percentage of building type in community composition (%)	Weightage
Residential	85.72	0.86
Office	3.46	0.03
Commercial	5.31	0.05
Hotel	0.00	0.00
Factory	0.42	0.00
School	4.59	0.05
Hospital	0.51	0.01

Appendix 42 Weightage assigned for each power component for Toyosu town

Generation category	Generation type	Max power generation (kW)	Weightage by considering individual category	Weightage by considering all categories
Stable	Oil	129200	0.24	0.77
	LNG+LPG	193800	0.35	
	Coal	96900	0.18	
	Nuclear	64600	0.12	
	Hydroelectric	64600	0.12	
Storage-based	PS Hydroelectric	32300	0.21	0.22
	Storage 1	15473	0.10	
	Storage 2	18480	0.12	
	Storage 3	53708	0.35	
	Storage 4	15272	0.10	
	Storage 5	18637	0.12	
Intermittent	PV1	1189	0.10	0.02
	PV2	2539	0.22	
	PV3	3015	0.26	
	PV4	2477	0.21	
	PV5	2577	0.22	

Network type	Weightage
Feeder	0.6
Primary	0.4

Building type	Percentage of building type in community composition (%)	Weightage
Residential	37.92	0.38
Office	27.98	0.28
Commercial	23.41	0.23
Hotel	0.00	0.00
Factory	1.53	0.02
School	7.44	0.07
Hospital	1.72	0.02

Appendix 43 Weightage assigned for each power component for Kitakoujiya town

Generation category	Generation type	Max power generation (kW)	Weightage by considering individual category	Weightage by considering all categories
Stable	Oil	7400	0.24	0.73
	LNG+LPG	11100	0.35	
	Coal	5550	0.18	
	Nuclear	3700	0.12	
	Hydroelectric	3700	0.12	
Storage-based	PS Hydroelectric	1850	0.21	0.21
	Storage 1	2996	0.34	
	Storage 2	4083	0.46	
Intermittent	PV1	1283	0.43	0.07
	PV2	1704	0.57	

Network type	Weightage
Feeder	0.6
Primary	0.4

Building type	Percentage of building type in community composition (%)	Weightage
Residential	72.41	0.72
Office	4.77	0.05
Commercial	1.97	0.02
Hotel	0.00	0.00
Factory	18.51	0.19
School	2.14	0.02
Hospital	0.20	0.00

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