The Ecosystem of Renewable Energy Shift and its Future Dynamics

by

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ABSTRACT

Substituting non-renewable energy for renewable energy plays an important role for our sustainability, which is the common goal for human beings. However, several strategies by governments and companies exist to make this shift, because the priority of each strategy mainly depends on the relative costs and their regulations, which makes this shift complicated. This paper describes a model of the common causal loop diagram and applies it to three cases. Additionally, by building stock and flow model, the future dynamics are simulated by System Dynamics.

Based on the casual loop diagram analysis, the renewable shift makes three phases. The first phase is making an ecosystem of renewables initiated by political support or guideline such establishing a low generation cost and making the power grid system flexible enough to accept renewables. The second phase is pushing the energy mix by private investment to capture the economic benefit including reducing electric bills with low-cost renewable energy, the merit of reputation and sustainability of business. The third phase aims at meeting the political target of the energy mix by political strategies, such as tax exemptions, subsidies and obligations for companies.

Stock and flow model of System Dynamics is applied for the future of the Japanese renewable shift cases to illustrate which compositions of the casual loop are the key causes for dynamics. At first, the relative cost triggers the renewable shift not only for companies but also for utilities. After that, the difference of the energy mix of a company and its target decides how much the energy mix increases each year. These two factors decide the intensiveness of investment of a company, even though the relative cost is not an internal factor. Also, the capacity mix of a utility deals with the speed of the renewable shift.

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Two years ago, when I started my MIT life, I was really overwhelmed by the intensiveness of the SDM Boot camp and SDM core course. Additionally, the other classes required many assignments. There is no doubt that the August and September in 2016 was the toughest time in my life. However, Lecturers, TAs, SDM friends, Japanese friends and my family truly supported me. I would like to thank all of the people who encouraged me in my MIT and Cambridge life.

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Masahiro Yamada
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LIST OF ACRONYMS AND ABBREVIATIONS

ANRE	Agency for Natural Resources and Energy
CLD	Casual Loop Diagram
EU	Europe Union
FEPC	Federation of Electric Power Companies
FIT	Feed-in Tariff
GCWG	Generation Cost Working Group
GHG	Greenhouse Gas
IEA	International Energy Agency
INDC	Intended Nationally Determined Contributions
LCOE	Levelized Cost of Electricity,
LTS	Longitudinal Transmission System
METI	Ministry of Economy, Trade and Industry
MTS	Mesh Transmission System
NS	Nederlandse Spoorwegen
OCCTO	Organization for Cross-regional Coordination of Transmission Operators,
O&M	Operation and Maintenance
PPA	Power Purchase Agreement
REC	Renewable Energy Credit
TGC	Traceable Green Certificate
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 1 Introduction

1.1 Motivation

Increase of the Energy Consumption

Throughout history, population growth has increased the demand of energy consumption. Starting to use coal triggered the acceleration of energy consumption after the Industrial Revolution. Also, expanding the usage of oil accelerated in 1960s. Figure 1.1 [1] indicates that this accelerating trend will last for the future.

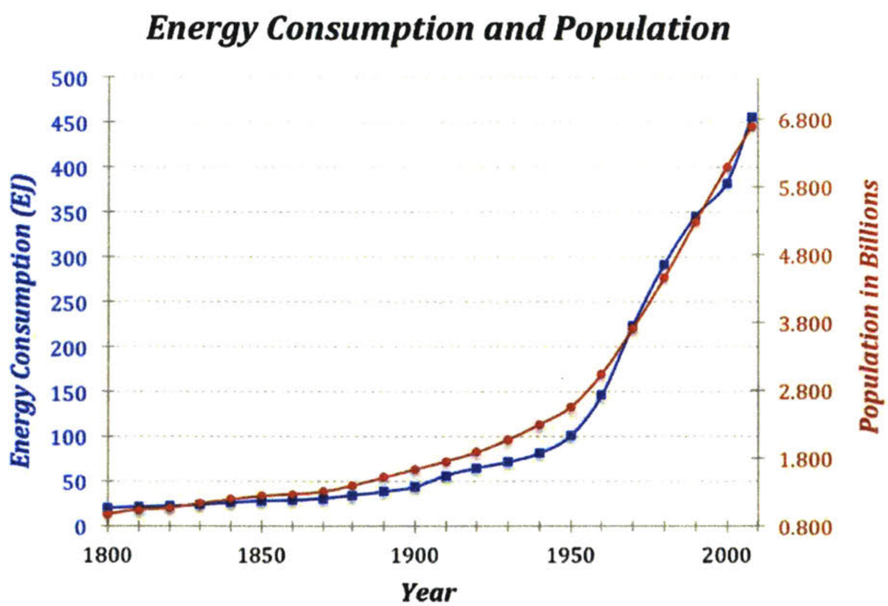


Figure 1.1: Transition of Population and Energy Consumption

(Source: Earth 104)

Limitation of Traditional Energy

Most electricity is generated by fossil fuels such as coal, natural gas and oil (Figure 1.2 [1]), but these sources have negative effects on the environment, including global warming--one of the biggest challenges facing human beings–and the increase of greenhouse gas emissions caused by the burning of fossil fuels. Additionally, even though new oil fields and new a type of fossil fuel (shale gas) have been identified, these resources are limited. As a result, using fossil fuels creates two problems: pollution of the environment and a draining of the existing fuel supply. These limitations indicate that the traditional energy cannot sustain human activities in the same way for the future.

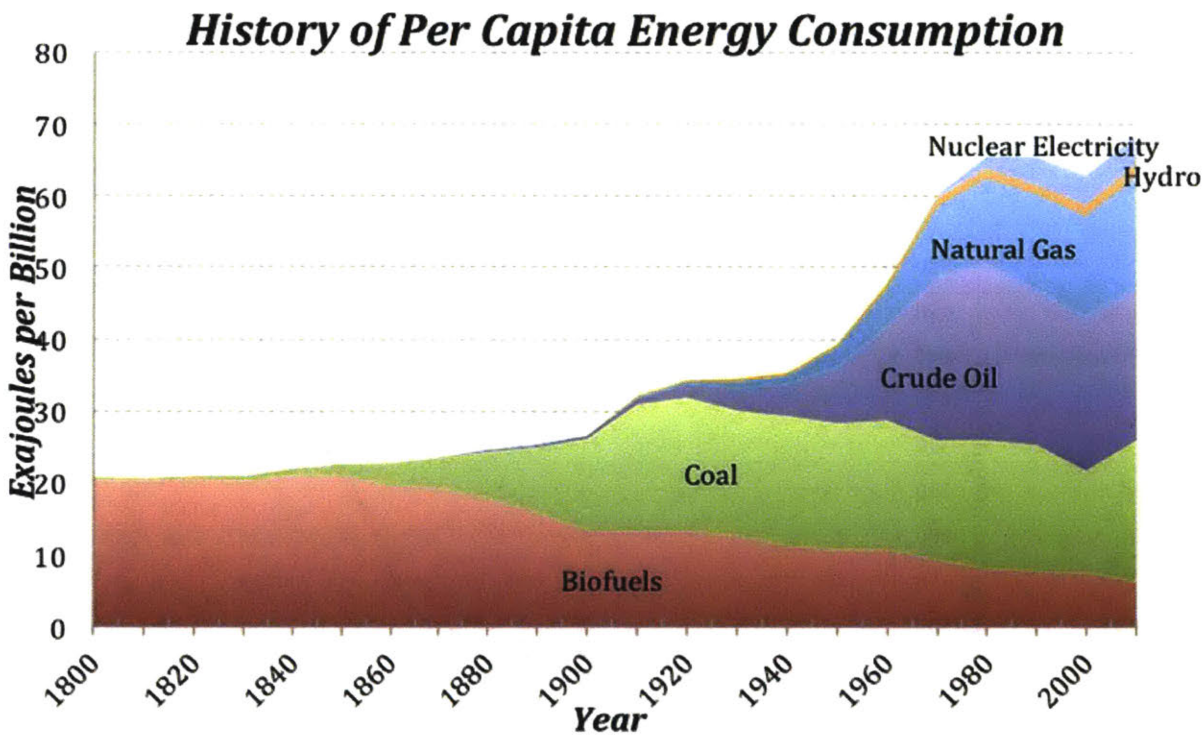


Figure 1.2: Historical Energy Consumption

(Source: Earth 104)

Shift to Renewable Energy

Several methods exist for preventing the negative impact for the Earth, such as saving energy or using carbon offsets. However, consuming renewable energy instead of traditional energy (hereafter, the renewable shift) is the most effective strategy when considering the sustainability of human activity and the environment of the Earth. One strategy is a power purchase agreement, which is the collaboration project between a company and a utility, and this strategy requires the flexibility of the grid system. Another strategy is purchasing a Traceable Green Certificate (TGC), which does not require the grid system conditions, but TGC contains market risk. Thus, each strategy has a sweet spot based on the circumstances of electricity industry and the policy climate.

1.2 Research Objectives

In this paper, the energy mix of a company is the main criterion of the renewable shift (i.e., how a company can increase its renewable energy instead of using traditional energy). Organizing the characteristics of several renewable shift strategies and showing their dynamics are the objects of this paper. This is because, in terms of the strategies of renewable energy shift, political sectors and public organizations introduce a variety of strategies, but there are no strategies which are effective all the time.

In the sensitivity analysis part, this study focused on the renewable shift in Japan. According to the publication by the Agency for Natural Resources and Energy (ANRE) [2], the energy mix of Japan was lower than that of the EU in 2016, which is described in Figure 1-3 [3]. However, Japan has already achieved a higher energy efficiency than US, England, French and Germany. This fact weights the importance of the renewable shift because no other strategies than renewable shift are already relatively mature. Additionally, Japan is now reorganizing the utility industry for 2020, separating the generation part and the power grid system, which brings more dynamics to the renewable shift. This reorganizing aims at increasing the flexibility of the infrastructure (i.e., increasing the capacity and opportunities of interconnection for the next power grid system). For these reasons, the dynamics of the renewable shift are Japan is appropriate for applying this model and analyzing it for future recommendations.

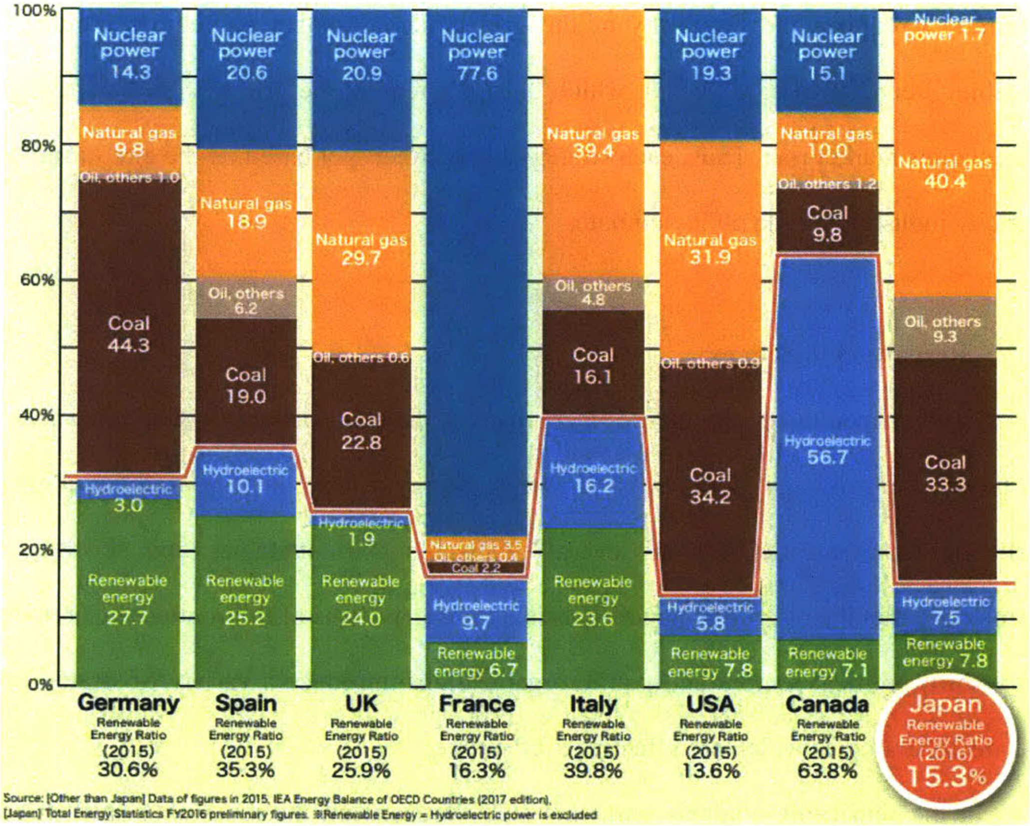


Figure 1.3: Comparison of the Renewable Energy Ratio in the Generated Electric Power Amount

(Source: ANRE)

1.3 Research Questions

The followings are the key questions of this thesis.

- What are the common features and differences in the renewable shift projects?
- Who leads and invests for the renewable shift?
- What factors accelerate the renewable shift?
- How do renewable shift dynamics behave?

1.4 Approach

The approach to the renewable shift in this paper is divided into three steps. The first step is to present the common procedures of the renewable shift by breaking it down into three phases based on the literature review, illustrated in the Causal Loop Diagram (CLD). The second step is to identify the differences of the three cases of renewable shift based on the strategies of each case, which are also presented in the CLD. The third step is to show the dynamics of the shift by stock and flow model of System Dynamics.

1.5 Thesis Outline

This thesis is organized as follows. Chapter 2 introduces both political and private methods to increase the usage of renewable energy, and the key factors. Chapter 3 analyzes the case and results of the renewable shift by Casual Loop Diagram, and also shows some phases for the renewable shift and the different key feedback loops of dynamics by applying CLD for some cases. Chapter 4 shows the stock and flow model of the renewable shift to consider the dynamics and interaction of company, utility and the related factors. The results of the renewable shift are analyzed to evaluate results and make forecast to prevent the future risk. Chapter 5 summarizes the key findings of this research and makes some recommendations for companies.

Chapter 2 Strategies of Renewable Shift and Key Factors

2.1 Political Approach

2.1.1 Paris Agreement

The Paris Agreement is the first framework agreed by representatives of 196 parties of the United Nations Framework Convention on Climate Change (UNFCCC) on December 12, 2015. The purpose of the Paris Agreement is to mitigate global warming by settling the long-term temperature goal. The Paris Agreement also mentioned the global peaking shift, reaching global peaking of greenhouse gas emissions (GHGs).

For these goals, each country decided their own contributions, which were described as the Intended Nationally Determined Contributions (INDC). countries will submit their INDC every five years; the next submission will be 2020. The targets of all the countries submitted in 2015 are summarized in Table 2.1 [4].

Table 2.1: Intended Nationally Determined Contributions (INDC) in Paris Agreement as of 2015

Country	Reducing Target
USA	Reducing GGE by 26-28% based on 2005 by 2030
*EU	Reducing GGE by 40% based on 1990 by 2030
China	Setting GGE peak to approx. 2030 (Effort to shift peak earlier) Reducing GGE/GDP by 60-65% based on the 2005 by 2030
Japan	Reducing GGE by 26% based on 2013 by 2030, and 25.4% based on 2005 by 2030
India	Reducing GGE/GDP by 33-35% based on the 2005 by 2030

(Source: UNFCCC)

*EU and its Member States: Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, United Kingdom

2.1.2 Political Target for Each Sector

Based on the Paris Agreement, some countries settled the breakdown target for each sector. In case of the Japanese government, the Ministry of Environment indicated the targets of GGE for each industrial sector. Table 2-2 [5] shows the CO2 emission target of each sector. Additionally, since using more renewable energy and thoroughly saving energy is one of the important strategies for reducing GGE, the energy mix was also set as the target for the Paris Agreement by Japanese government. Figure 2.1 [6] presents the detail targets of energy mix and energy saving. However, there is no obligation of failing to reach to these targets as of 2017.

Table 2.2: Target of CO2 Emission in 2030 in Japan

	Target of 2030 [Mton]	Result in FY2013 [Mton]	Result in FY2005 [Mton]
Industrial Sector	401	429	457
Non Industrial Sector	122	201	180
Transportation Sector	163	225	240
Utility	73	101	104

(Source: Ministry of Environment)

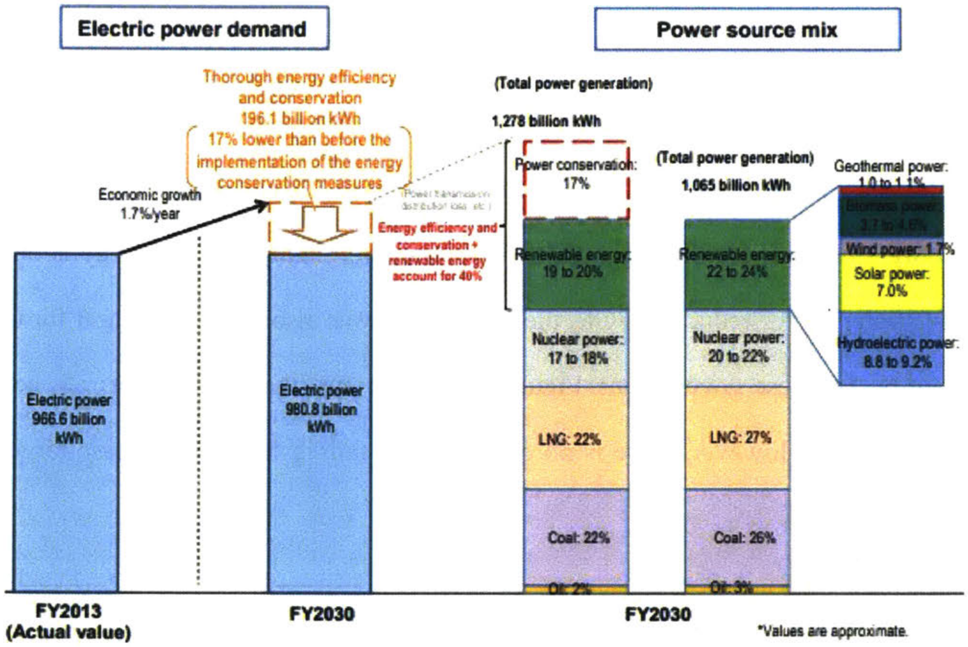


Figure 2.1: Energy Mix of Japan (FY2013 is result and FY2030 is target)

(Source: ANRE)

2.1.3 Feed-in Tariff (FIT)

Feed-in Tariff (FIT) is the policy mechanism to accelerate the usage of renewables and provide inexpensive cost for consumers. The generators can sell as much as of their renewable energy as they produce at the fixed price for a long time, because producers are applied to the long-term contract guaranteed by government. Also, the government can adjust the selling price to the technology progress or climate of each renewable. The difference cost of fixed price and actual generating price are compensated for by all electricity consumers based on their consumption volume [7]. This framework reduces the uncertainty of the investors of renewables.

The benefit of FIT is not only accelerating the investment for renewables and increasing the usage of renewables, but also reducing the traditional energy. Due to the FIT, the price of electricity from renewables can be cheaper than that from the existing non-renewables such as thermal power.

In contrast, the negative point of FIT is that it may trigger a dramatic increase of renewables over the grid capacity. Since the output of renewables fluctuates, producers sometimes generate more than demand and sometimes cannot generate more than expected. This point is discussed in Section 2.3.2 as the Japanese case in this thesis.

FIT in Japan

The Japanese government decided to introduce FIT for solar power in 2009 and spread it to all renewable energy in 2012. Figure 2.2 [8] shows the effects of FIT in Japan. Before FIT started, two schemes to increase renewable energy were available in Japan, Renewable Portfolio Standard System and Excess Electricity Purchasing Scheme. These schemes brought the 5%-9% growth rate of renewable energy, but FIT accelerated the growth rate more [8]. Figure 2.3 [8] illustrates the decreasing of the FIT price which is forecasted to be equal to the household electricity price in 2019. These two figures present the turning point of FIT in Japan. In fact, Japanese government revised the existing FIT in 2017, but FIT still plays an important role to push forward the energy mix in Japan.

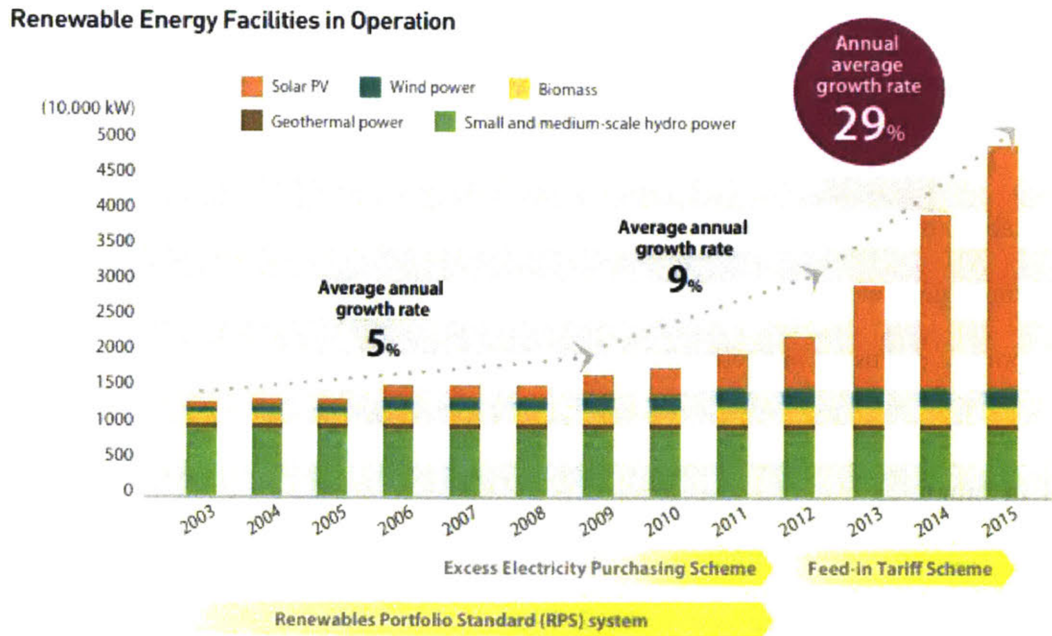


Figure 2.2: Renewable Growth in Japan after FIT Started

(Source; METI)

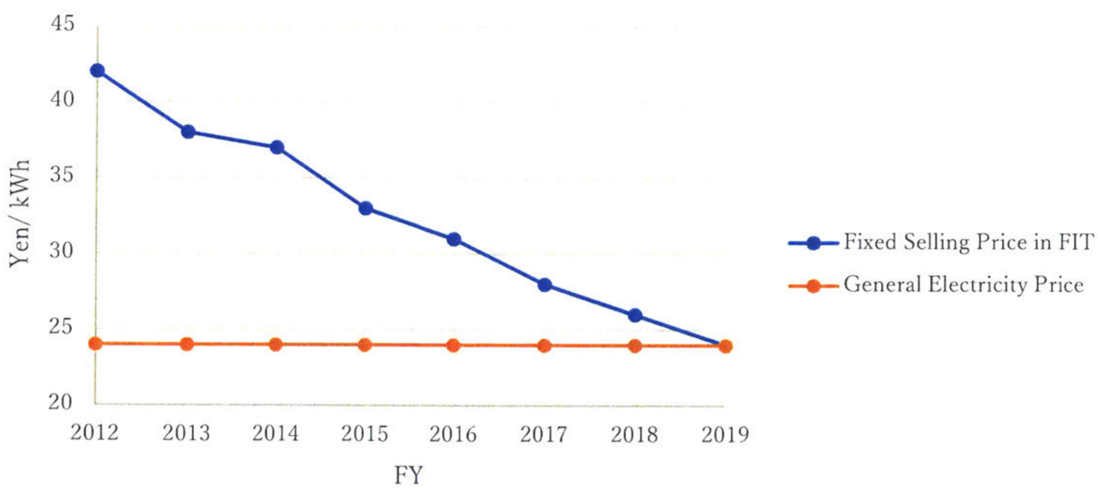


Figure 2.3: Comparison of FIT Price and General Electricity Price

(Source; METI)

2.2 Private Approach

2.2.1 RE100

RE100 was established in 2014 by The Climate Group (an NGO) as the global initiative for consuming only renewable energy. The goal of The Climate Group is "A world of under 2°C of global warming and greater prosperity for all, without delay" [9].

According to the annual report of RE100 in 2017, 87 companies joined RE100. The companies of RE100 have the diversity of industry, which is shown in Table 2.3 [10]. RE100 shares the knowledge and business information of renewables for the RE100 members such as strategies of dealing with energy costs. The members of RE100 decided their goals on their own. Table 2-4 [11] presents the examples of the targets of RE100 members.

Table 2.3: Breakdown of RE100 Members in 2017

Sector	Number of Members
Financials	23
Consumer Discretionary	17
Information Technology	15
Industrials	11
Consumer Staples	8
Materials	6
Health Care	4
Telecommunication Services	3
Total	87

(Source: RE100)

Table 2.4: Goal of RE100 Members

Company	Nationality	Industry	Target	Notes
Google	US	IT	2017	Achieved 100% renewable energy in 2017
Bank of America	US	Bank	2020	100% renewable electricity by 2020.

UBS	Switzerland	Bank	2020	100% powered by renewable energy by 2020
Anheuser-Busch InBev	Belgium	Brewer	2025	100% of the company's purchased electricity from renewable sources by 2025.
ASKL	Japan	Logistics	2030	Long-term goal; 100% renewable electricity by 2030. Interim goal; 80% by 2025.
Unilever	British, Dutch	Consumer products	2030	100% of electricity purchased from the grid from renewables by 2020. Sourcing 100% of its energy from renewables by 2030.
Adobe	US	IT	2035	Entirely renewable electricity by 2035
DAIWA HOUSE	Japan	Housebuilders	2040	100% renewable electricity by 2040.
RICOH	Japan	multinational electronics	2050	Long-term goal; 100% renewable electricity by 2050. Interim goal; at least 30% by 2030.

(Source: RE100)

2.3 Key Factors to Energy Shift to Renewables

2.3.1 LCOE

Levelized Cost of Electricity (LCOE) can measure the lifetime costs of all generators and calculate the present value of the total cost including building and operating a power plant thorough their lifetimes. Because of these features, LCOE widely spread to evaluate the cost of several electricity sources. The calculation method of LCOE is defined as the difference cost of the total revenue and lifecycle expense divided by its total generating volume; thus, the unit of LCOE is \$/kWh. This calculation reflects the idea of present value and discount rate. Figure 2.4 [12] describes the simple concept of LCOE, and LCOE is calculated as below. [12]

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t = Investment expenditures in year t (including financing)

M_t = Operations and maintenance expenditures in year t

F_t = Fuel expenditures in year t

E_t = Electricity generation in year t

r = Discount rate

n = Life of the system

(Source DOE)

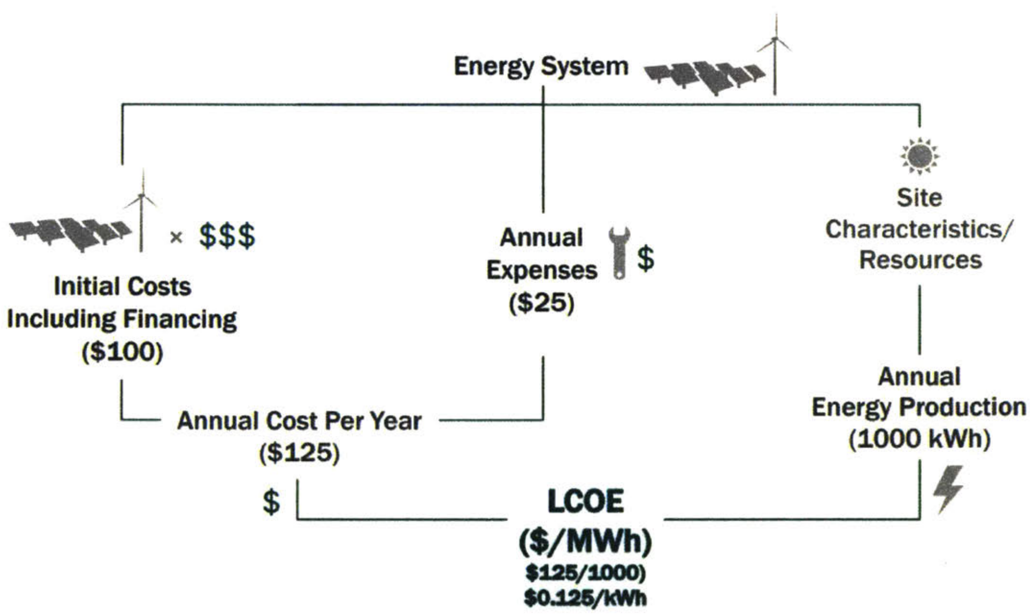


Figure 2.4: Simple Concept of LCOE

(Source DOE)

High generation cost of renewables in Japan rather than non-renewables

Generation Cost Working Group, subcommittee of the ANRE organized, published the examinations of the generation cost of Japan based on LCOE. This examination includes the results in 2014 and the forecast of 2030, which is summarized in Figure 2.5 [13]. The result is that the generation cost of renewables in Japan in 2014 was expensive than the traditional non-renewable. However, the renewables in Japan will decrease in 2030; generation cost of solar power will be approximately that of coal, and that of wind power will be approximately that of LNG.

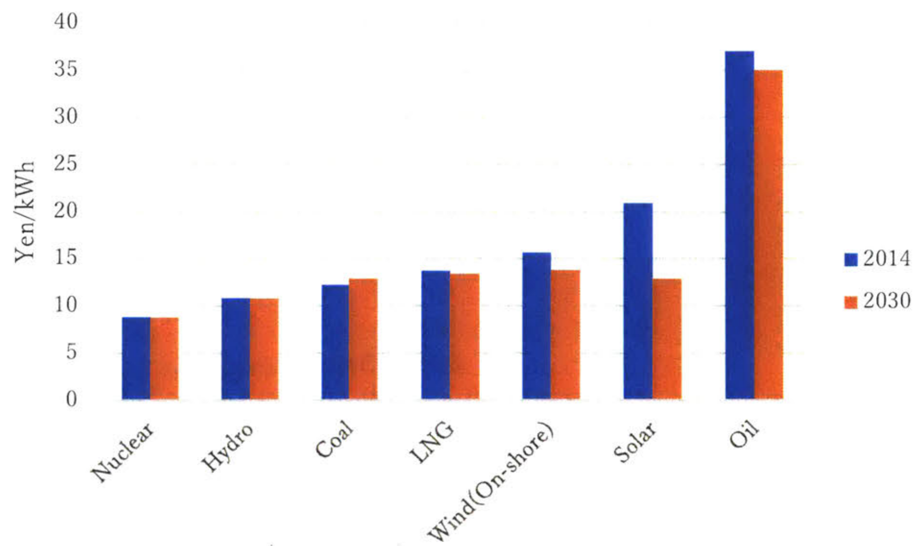


Figure 2.5: Generation Cost of Japan in 2014 (Results) and in 2030 (Forecast)

(Source: GCWG)

High Generation Cost of Renewables in Japan compared to other Countries

Table 2.5 [14] [15] presents the comparison of renewable generation cost in other countries and shows the cost of renewables in Japan is more expensive than in other countries. Especially, the capital cost and Operation and Maintenance (O&M) cost are the main factors of high generation cost in Japan. For example, the O&M cost of solar in Japan is double that of Germany, for two reasons: undeveloped O&M restriction in Japan, and maintenance labor cost. Several O&M companies exist in Japan, which is the result of no convergence of O&M service and price standard. Also, the safe regulation in Japan requires a utility to have an

Electric Chief Engineer, as prescribed by Electric Industry Law. The Electric Chief Engineer must obtain a license from METI based on the utility's voltage, as described in Table 2.6 [16]. This certificate system of Electric Chief Engineer is unique in Japan and pushes the O&M labor cost.

Table 2.5: Cost Comparison of Solar Power and Wind Power in 2016

	Solar			Wind		
	Generation Cost [$/MWh]	Capital Cost [$/MWh]	O&M [$/MWh]	Generation Cost [$/MWh]	Capital Cost [$/MWh]	O&M [$/MWh]
Australia	85	1,445	18	72	1,934	24
Brazil	111	1,381	24	67	1,710	30
China	102	1,181	12	76	1,345	15
England	130	1,160	32	85	1,765	24
France	93	1,050	32	80	1,516	30
Germany	103	1,000	32	79	1,897	26
India	90	898	17	77	1,070	16
Japan	192	2,205	68	156	2,611	37
Spain	148	1,390	36	91	1,516	26
Turkey	122	1,240	32	91	1,897	21
USA	87	1,427	21	65	1,501	26

(Source: METI)

Table 2.6: Electric Chief Engineer in Japan

Class	Permission to construct, maintenance and operation
First class Chief Electric Engineer's License	All voltage
Second class Chief Electric Engineer's License	Less than 170kV
Third class Chief Electric Engineer's License	Less than 50kV (except for plant which generates more than 5000kW)

(Source: METI)

2.3.2 Infrastructure Flexibility

The term infrastructure is used here to refer to the overall power sending system including the transmission wire and grid operation system. The manager of infrastructure has an obligation to maintain the voltage and frequency, which are usually regulated or standardized by the electricity power law of each company. Thus, just connecting to the transmission is not enough to increase the amount of transmission capacity.

Infrastructure has two types of systems; Mesh Transmission System (MTS), and Longitudinal Transmission System (LTS). Figure 2-6 [17] illustrates that the infrastructure of the EU is the appropriate example of MTS and that of Japan of LTS. Each system has both advantages and disadvantages. As Figure 2-7 shows, since the MTS has more path than LTS, connecting to other grid systems by MTS is relatively unchallenging compared to LTS under the circumstance of a sophisticated control system. However, once an accident happens, LTS can recover from an outage relatively faster than MTS because the electricity flow of LTS is simpler than MTS, taking less time to find the point of accident and the way to recover. As of 2018, the infrastructure of Europe still has the plan to grow by 2040 to increase their flexibility. [18]

Especially for Japanese infrastructure, not only LTS, but the difference of frequency also increases the difficulty of connecting to the next grid. The frequency of the east part of Japan is 50Hz, and that of the west part is 60Hz. This is because the electricity company of east part of Japan that started their business in Tokyo and referred to Germany's standard, 50Hz. On the other hand, that of west side launched their business in Osaka and referred to the US standard, 60Hz. Since then, the Japanese economy has developed, sprawling from the larger cities, Tokyo and Osaka, and the infrastructure of electricity was developed as well. Thus, Japan still has the two types of frequency, which ss the unique point in Japan to prevent it from connecting to the next grid.

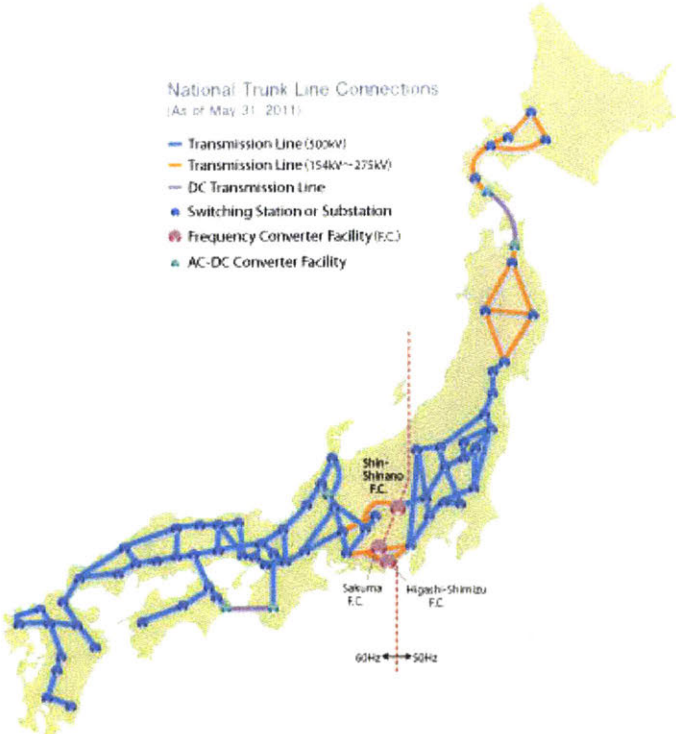


Figure 2.6: LTS in Japan

(Source: FEPC)

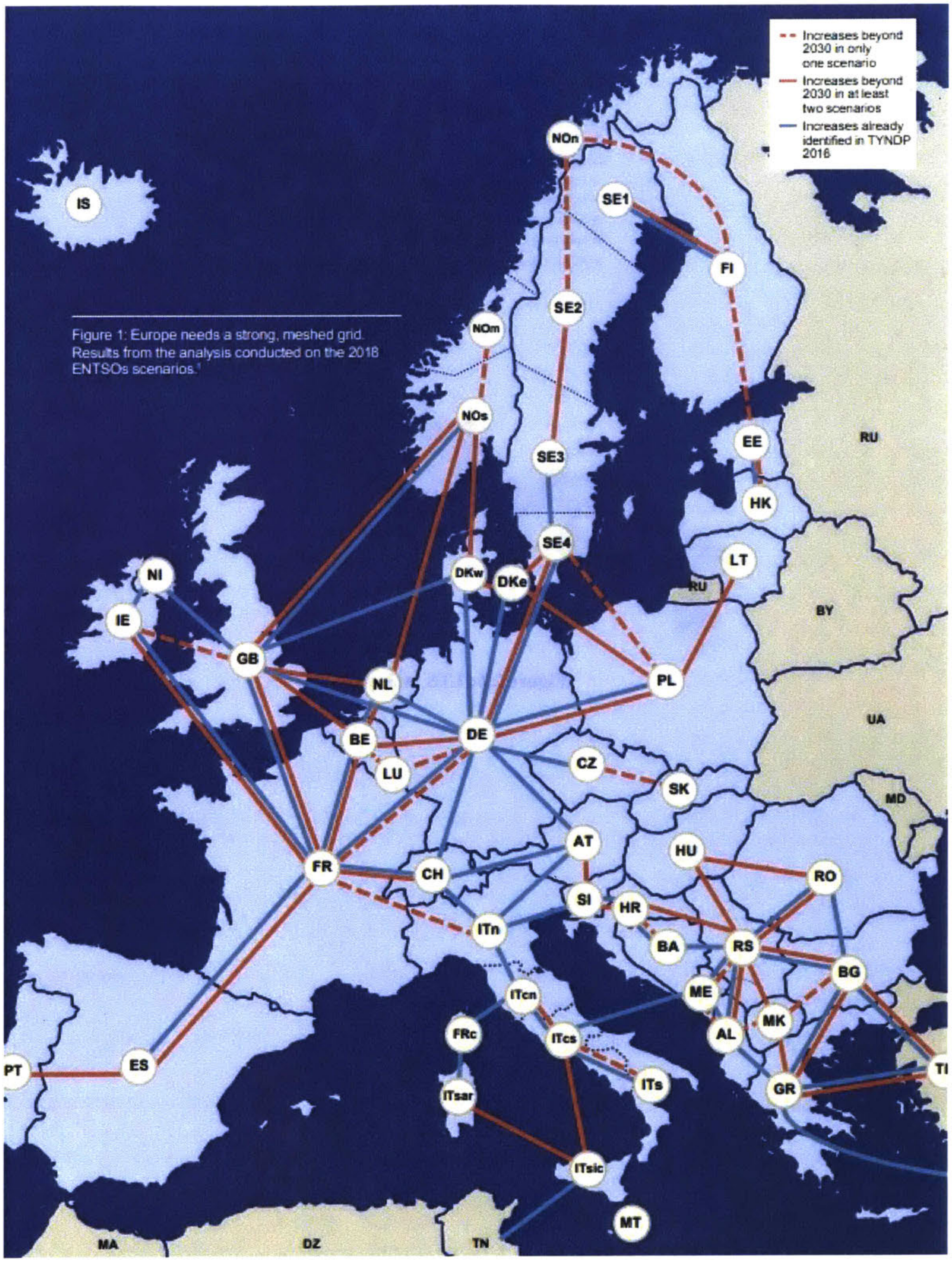


Figure 2.7: Existing MTS and future investment in EU

(Source: entsoe)

2.3.3 Power Purchase Agreement (PPA)

Power Purchase Agreement (hereafter, this is called 'PPA') is used in a broadly meaning in this thesis and defined as the contract between utility and electricity consumer. PPA is one of the contract of financial arrangement and usually lasts for a long term. Not only purchasing electricity from utility, but the companies can select the source of electricity including renewables. In this thesis, PPA of renewables plays an important role because this contract has benefit for each other especially reducing uncertainty.

The contract conditions depend on the purpose or power balance of company and utility. For electricity consumers, PPA usually guarantees the electricity price and volume from renewables during its validation, which reduces the price and volume risk. For utility, since the demand of renewable guaranteed by the contract, the uncertainty of investment reduces.

2.3.4 Traceable Green Certificate (TGC)

Traceable Green Certificates (TGC) is the method by which the added value of renewable energy can be securitized, and TGC can trace the rights of the contribution to environmental protection. TGC is sometimes described as Renewable Energy Certificate (REC). The basic idea of TCG and REC is that the electricity from renewable energy has two values: electricity and less environmental damage, and the latter environmental value can be securitized and tradable. As the consumers purchase the TGC when they use the electricity from a non-renewable source, their electricity usage from the non-renewable can change to that from renewables with a premium. The premium reduces the generation cost of renewables for the utility. In Japan, the price was 3-4 yen/kWh in 2016 [19]. The characteristics of TGC and REC are summarized in Table 2-7.

Table 2.7: Characteristics of TGC

Positive Points	Negative Points
- No need to construct the power plant of renewables. - Easy entry/withdrawal	- Market Risk - Need distribution cost of security (i.e. reducing the subsidize for renewables)

2.3.5 Carbon Offset and Cap & Trade

The main idea of Carbon Offset is that absorbing greenhouse gas anywhere can offset the GGE from human activity. Planting trees or replacing inefficient machines with high energy efficient machines are the examples of carbon offset.

Cap & Trade enables a utility to emit GGE more than the assigned amount by buying carbon credit. In this thesis, since the basic idea of Carbon Offset and Cap & Trade is focused on reducing GGE directly and not involved in electricity, Cap & Trade is dealt with as Carbon Offset.

Table 2.8: Purpose and Means of PPA, TGC, Cap & Trade and Carbon Offset

	To	by	Note
Carbon Offset	Offset CO2 emissions	Absorbing CO2 (ex. planting trees)	Not involved in Electricity
Cap & Trade	Offset CO2 emissions	Trading the amount of carbon emission	Not involved in Electricity
PPA	Reduce using electricity energy from fossil fuels	Purchasing renewable energy from utility	
TGC	Offset using electricity energy from fossil fuels	Purchasing securities from the market	

Chapter 3 Causal Loop Diagram Analysis

3.1 Description of the CLD model

The purpose of this chapter is to use the renewable shift causal loop diagram of System Dynamics to illustrate the difference of some cases of the renewable shift. As discussed in Chapter 2, public sectors and private organizations launched several targets. Also, the priorities of strategies for these targets depend on the political power balance and economic climate of each company. However, the goal of the energy shift is quite simple, which can be evaluated by the energy mix. Thus, dealing with all factors by causal loop diagram and showing the status of the energy shift are effective to compare renewable shift cases. Causal Loop Diagram analysis helps the discussion of companies eager to use more renewable energy. The overall CLD is shown in Figure 3-1 below.

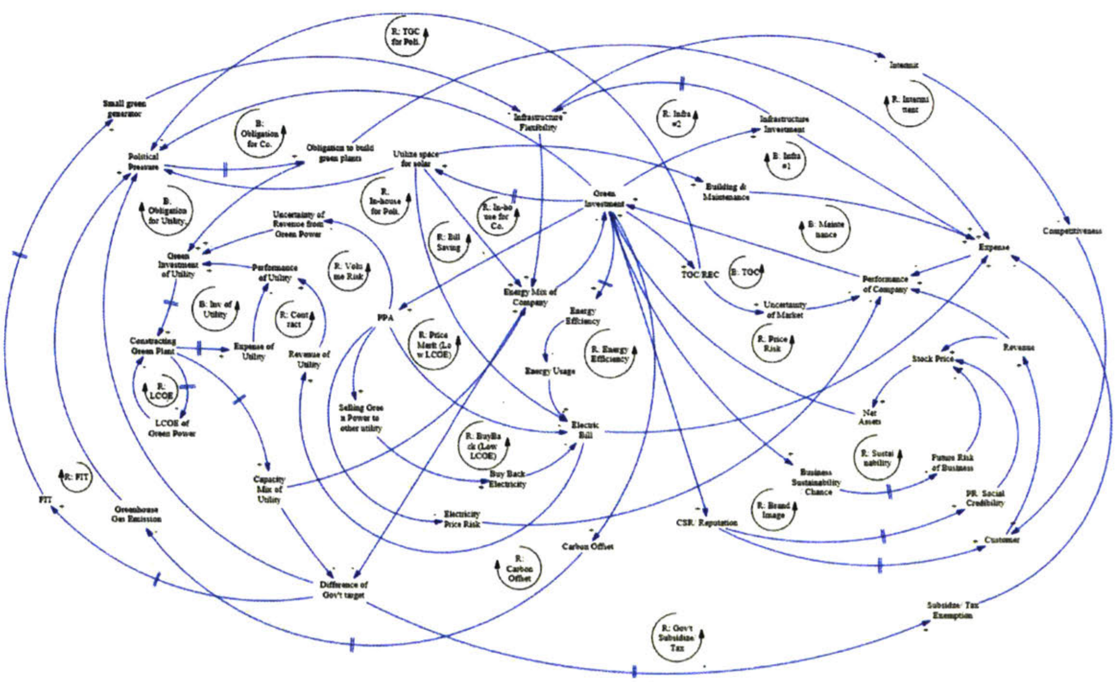


Figure 3.1: Causal Loop Diagram of Energy Shift to Renewables

3.1.1 Company Internal Loops

The Company Internal Loops are the subpart of CLD of Energy shift which is illustrated in Figure 3-1. This subpart is completed only inside companies, and is not related to utility, government, or infrastructure restriction. The main idea of this part is the motivation for the renewable shift of companies.

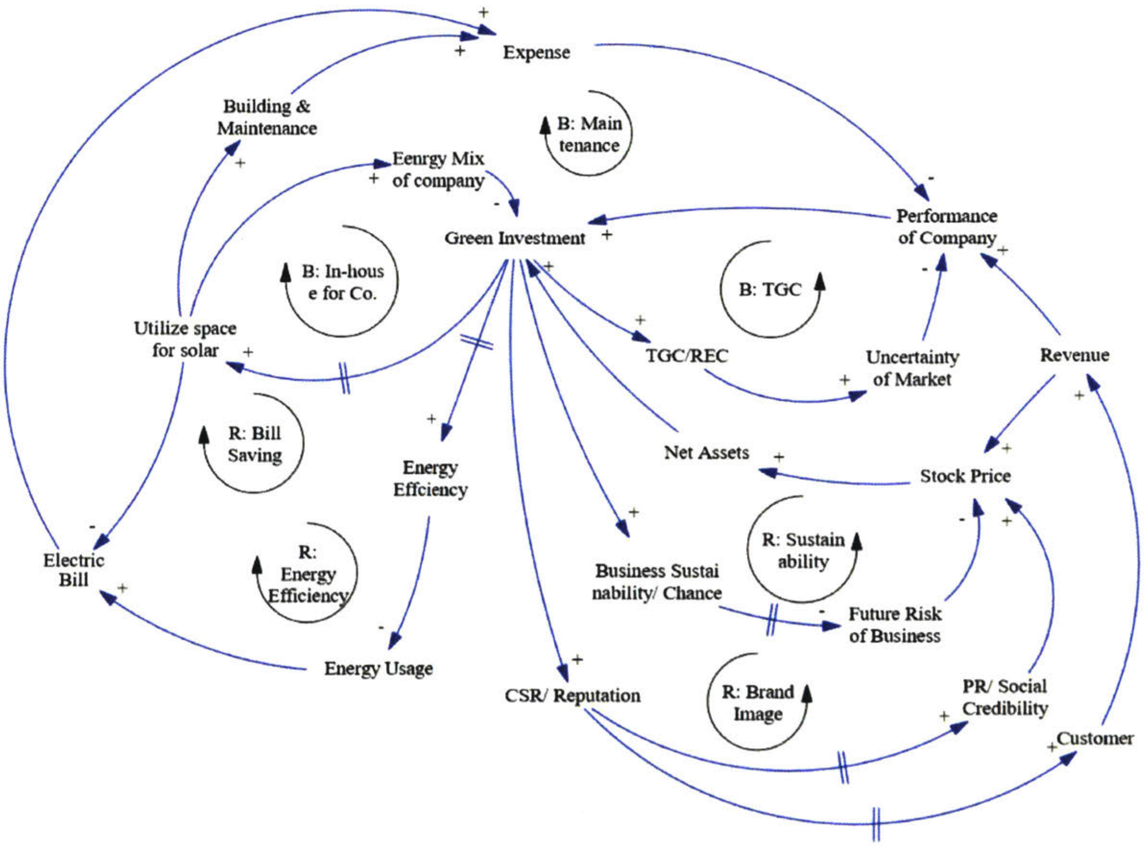


Figure 3.2: Causal Loop Diagram of the Company Internal Subpart

Reinforcing Loop: Sustainability

Green investment increases the business sustainability, which is a positive effect for the stock of companies. Additionally, the investment can bring to the new business opportunities. (e.g. some companies with the motivation for sustainability tend to corroborate with companies which also have the sustainability strategies if the other conditions are similar.), which increases the management sustainability because it can increase the revenue of the companies. Although there is a delay time for establishing this investment, the stock price and net assets can result in growth.

Reinforcing Loop: Brand Image

This loop describes the simplest motivation of a company for a renewable shift. Green investment is well known to improve the reputation of companies and increase social credibility, which are the trigger for increasing of customers with delay. As a result, the revenue and stock price are stimulated to increase.

Reinforcing Loop: Energy Efficiency

Saving energy is one of the famous ways to reduce the amount of energy bought. Replacing old equipment, mitigating the usage of air conditioners, or changing to daylight saving time are the examples of this loop. However, since the investment of energy efficiency usually requires R&D, some delay exists. Also, since the limit of energy efficiency exist, this loop is not effective until the break though of related technology occurs if companies achieved some extent of energy saving.

Balancing Loop: TGC

The unique advantage of Tradable Green Certificates (TGC) for the renewable shift is a simple framework; the only thing companies need to do is make a judgement about whether the price of TGCs is reasonable for the green investment of the company. This feature means that there is no need to consider the infrastructure or political subsidies; thus, companies can decide by themselves. However, since TGC is traded in the market, the price fluctuation risk exists, which is illustrated as "Uncertainty of Market" and makes the "Performance of Company" weaker.

Balancing Loop: In-house for Co

Reinforcing Loop: Bill Saving

Balancing Loop: Maintenance,

These loops apply to the following situations: laying solar panels on roofs or idle space, and building wind power generators by themselves. As these renewables usually are consumed at the office under the solar roof or next to the wind power, this improves the energy mix of the company regardless of the infrastructure. Also, the amount of electricity purchased from the utility decreases. As the construction time is required for this loop before starting its operation, a delay exists in this loop. Under these types of investments, companies have an obligation to maintain the renewables, which usually use outside professional sources and increase the expense of the companies

3.1.2 Relationship Loops of Company and Utility

The Relationship Loops of Company and Utility are also the subparts of the CLD which is illustrated in Figure 3-1. This subpart is focused on how to contact Power Purchase Agreement, PPA, and how to deal with the PPA to increase the energy mix.

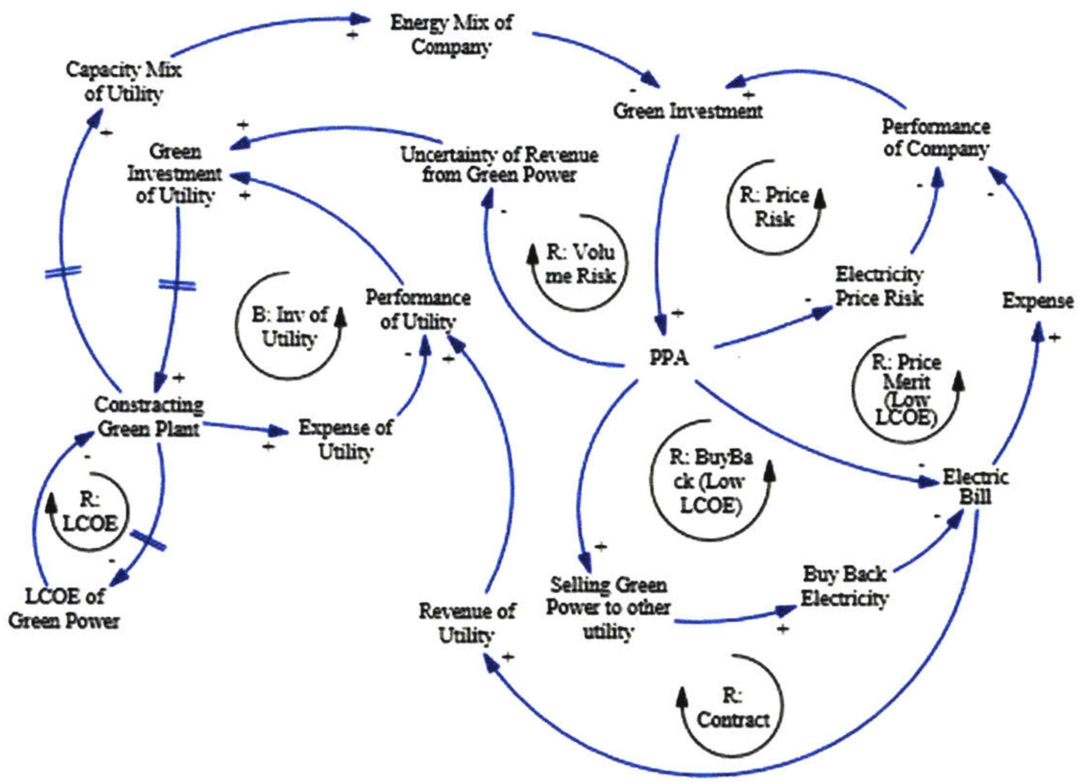


Figure 3.3: Causal Loop Diagram of the Relationship Loops of Company and Utility

Reinforcing Loop: LCOE

Constructing green power plants stimulates the investments in related materials and devices for green energy, which decreases the supply cost. Also, as the number of projects for building green power plants increases, the cost of construction decreases, and the duration of construction decreases. All these points make the LCOE of green power lower. This lower

LCOE incites the investment for constructing green power plants.

Reinforcing Loop: Price Merit (Low LCOE)

Some green power purchase agreements decide the price and amount of electricity beforehand; thus, the results of negotiation of electricity price can change this loop to reinforcing under the circumstance of low LCOE. If this price is cheaper than other sources of electricity, this loop is a reinforcing loop.

Reinforcing Loop: Contract

The merit for a utility when the electricity price is fixed in a green power purchase agreement is that it guarantees future income. This reduces the uncertainty of utility management and can increase stock price in the market. As a result, net assets increase, and the utility can invest more for green power. As this investment accumulates, the capacity mix of the utility increases with the delay of construction duration; then it increases the energy mix of the companies.

Reinforcing Loop: Price Risk

If a company fixes the electricity price in agreen power purchase, the future electric price risk (i.e., price fluctuation) decreases. This means companies can change the variable costs to the fixed costs, which makes management easier and improves the performance of the companies.

Reinforcing Loop: Volume Risk

PPA provides the company and utility with the benefit of ensuring the energy volume.

After signing the contract, the volume of renewable energy is secured as long as the contract is valid. This makes the investment of renewable energy reasonable due to reducing the risk of uncertainty. A delay exists for two reasons: deciding the investment because the duration for building the team for green investment team is needed, and starting the construction because a few years are needed to start the operation of a green power plant.

Balancing Loop: Inv. of Utility

As a utility invests in green power, the expense of the utility increases, which results in a negative effect for performance of the utility.

Reinforcing Loop: Buy Back (Low LCOE)

A company can sell the green power that it purchased based on a green power purchase agreement, then consume the same amount of nonrenewable energy. This strategy can offset the CO2 emissions of a company. Even though strong regulation exists for new entry to green power generator, or the grid system is not mature, companies can offset their emissions. This strategy is effective where the LOCE is lower than traditional energy, because the difference of selling renewables and purchasing non-renewables can be a loss for the companies.

3.1.3 Relationship Loops of Company and Political Parts

The Relationship Loops of Company and Political Parts illustrates the interaction of the company and political influence including subsidizing and political pressure. (i.e. How government influences a private company by growing the ecosystem of renewables and pushing the energy mix to the political target.)

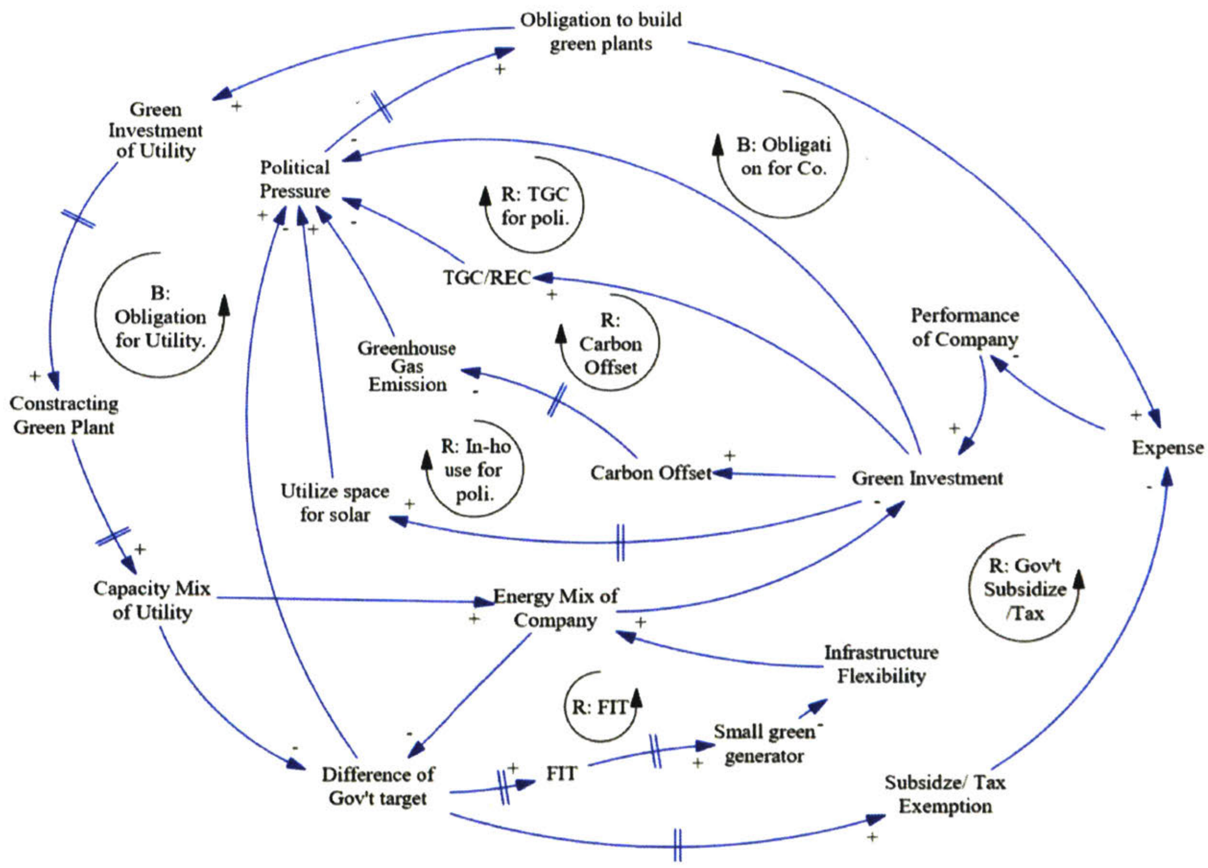


Figure 3.4: Causal Loop Diagram of the Relationship Loops of Company and Political Parts

Reinforcing Loop: FIT

When the energy mix is different from the target decided by the government, FIT, Feed-in Tariff, is one of the effective ways to increase the renewable supply, which usually has a delay due to the decision-making of the government. Based on the characteristic of FIT, FIT pushes the small green generator such as the private house, which sets the solar panel on the roof with the delay of setting the solar panel. Then, the increase from the small renewable generator makes the grid system more flexible, which enables a company to acquire the wide range of renewables.

Reinforcing Loop: Gov't Subsidy/Tax

When the energy mix is different from the target decided by the government, subsidies and tax exemptions with huge delay for decision-making are also effective ways to push the energy mix forward. These strategies reduce the expense of a company, so this is a reinforcing loop. However, subsidization and tax exemption can prevent economic competition and make the political power unbalanced. Thus, deciding the subsidization and tax exemption should be carefully considered; thus, this delay is huge.

Reinforcing Loop: In-house for poli.

Starting to consume in-house renewables increases the energy mix for a company, which reduces the political pressure.

Reinforcing Loop: TGC for poli.

Purchasing TGC/REC reduces the political pressure for a company and obligation for renewables, which reduces the risk factor to increase the future expense.

Reinforcing Loop: Carbon Offset

The carbon offset approach, such asgreening activity by planting trees, reduces the carbon gas emissions with a delay due to the growth of trees. After reducing CGE, the political pressure also decreases.

Balancing Loop: Obligation for Utility

Balancing Loop: Obligation for Co.

If the capacity mix of the utility is lower than the target of the government, the government may force the utility and company to invest the green power plant to increase the capacity mix, which increases the expense of them.

3.1.4 Relationship Loops of Company and Infrastructure

The Relationship Loops of Company and Infrastructure illustrate the interaction of the company and infrastructure including the flexibility of the grid system.

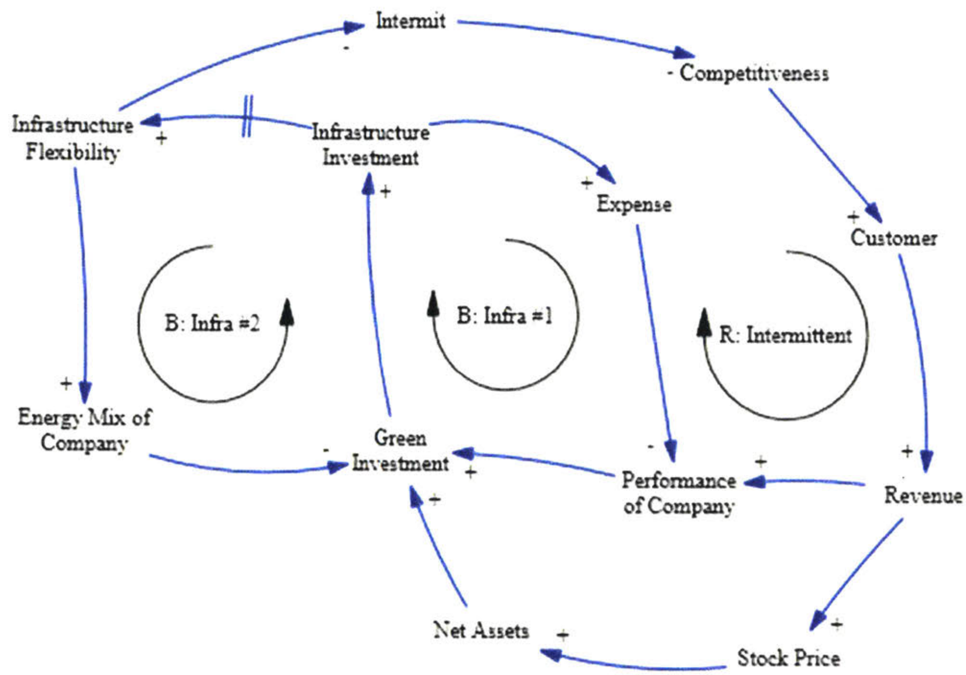


Figure 3.5: Causal Loop Diagram of the Relationship Loops of Company and Infrastructure

Balancing Loop: Infra #1

Green Investment of a company increases Infrastructure Investment, but it also increases the expense of a company. As a result, it affects Performance of company negatively.

Balancing Loop: Infra #2

Infrastructure Investment increases the flexibility usage of the grid system and makes power exchange easy. This increases the Energy Mix of company because a company can get a wide range of renewable sources. As the Energy Mix grows, the green investment decreases.

Reinforcing Loop: Intermittent

In general, the negative factor of using renewable energy is the intermittency of the electric supply, especially for companies with an immature grid system. Intermittency can prevent normal service for customers. As a result, the competitors of the companies are getting power for markets, and the revenue of the companies will decrease.

3.2 Application for Casual Loop Diagram

The purpose of application for Casual Loop Diagram is to illustrate the difference of some renewable shift cases based on their strategies and related circumstances of that renewable shift.

3.2.1 Case 1: NS and Eneco

Background of Case 1

Nederlandse Spoorwegen (NS) is the railway company of the Netherlands, and Eneco is a utility in the Netherlands. NS only provides railway transportation services for passengers. The maintenance of rail infrastructure and freight service operations are not within the scope of NS. The revenue of NS is 5.1 billion Euro in 2017. Also, NS operates international rail services from the Netherlands to nearby countries. [20]

Although an electric railway system already has advantages compared with other transportations in terms of environment, reducing greenhouse gas is still an important challenge for all industrial sectors including a railway company. NS achieved all their trains being operated by 100% renewable sources as of January 1, 2017 by the contracts with Eneco, which was the first and is still only case of a railway company operating its trains by completely green energy. As Eneco built the new wind power farm for the renewable shift of NS, NS can operate all their trains by green energy [21]. Furthermore, since the plan of the wind power construction by Eneco proceeded earlier than planned, the NS completed the energy shift in January 1, 2017 instead of 2018 [22] .

Energy Mix of the Netherlands

The Dutch government published the third white paper of energy policy in 1995, which aimed at energy liberalization. Then, the law of electricity was revised in 2004 and the Netherlands achieved the complete energy liberalization. [23] Figure 3.5 shows the transition of generating volume in the Netherlands after 2005. Figure 3.6 [24] shows the detail energy portfolio in the Netherlands in 2015. Only 1.2% of Energy is generated from renewables. As Figure 3.6 and Figure 3.7 [25] illustrate, analyzing the achievement of NS and Eneco provide several insights for companies that try to make a renewable shift, because renewable sources are not a main source in the electricity portfolio in the Netherlands.

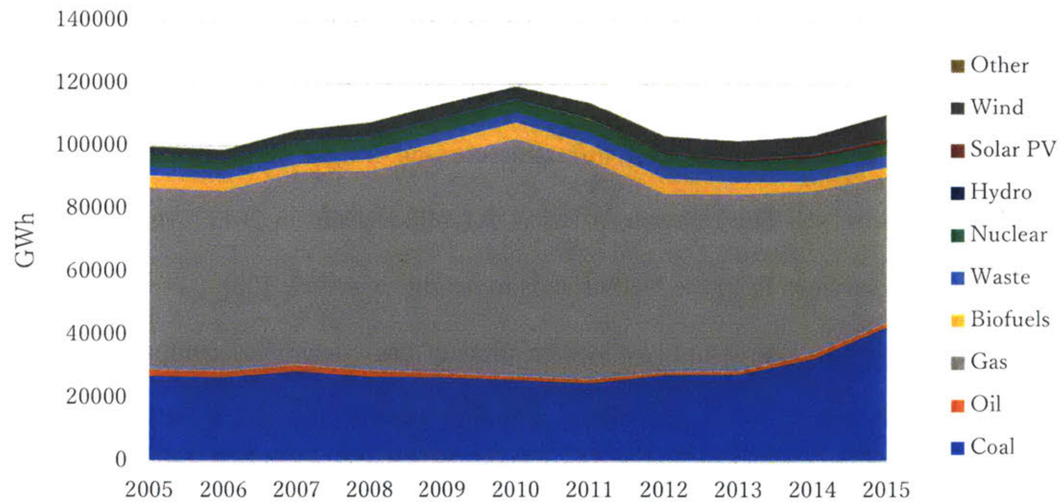


Figure 3.6: Transition of Electricity Generation in the Netherlands

(Source: IEA)

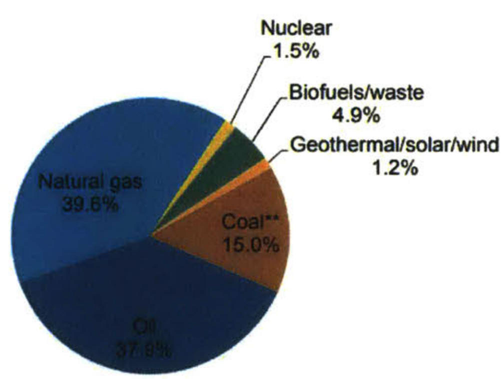


Figure 3.7: Energy Portfolio of the Netherlands in 2015

(Source: IEA)

Infrastructure (Grid System) of the Netherlands

The grid system in the Netherlands is connected to those of other countries. Figure 3.8 [24] shows that approximately 15%-30% of electricity is imported and the export of electricity grew from 5% to 20% in the last decade.

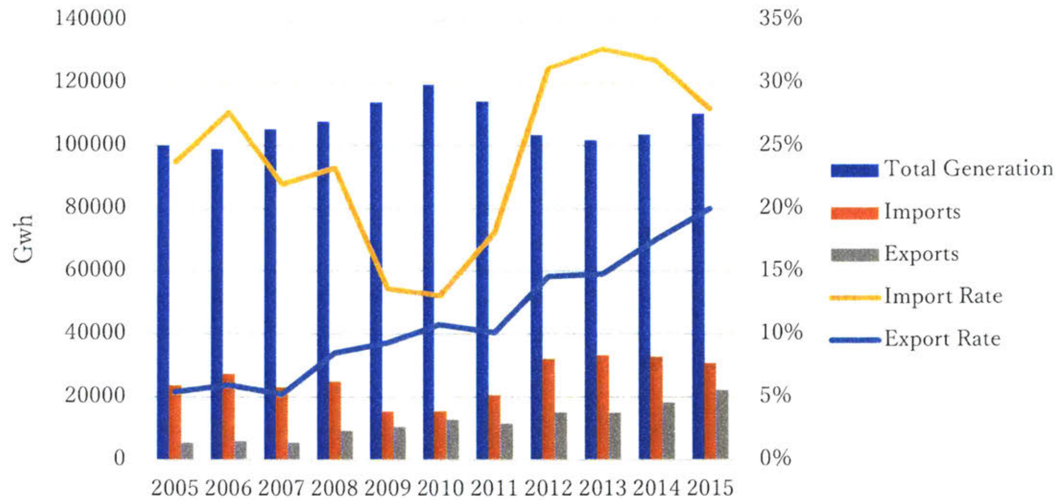


Figure 3.8: Export and Import of Electricity in Netherland

(Source: IEA)

Contract of NS and Eneco

NS signed a contract amounting to €194 million to Eneco for ten years (2015-2024) [26]. Although the energy mix of NS was relatively higher as early as 2015, which was approximately 50%, the purpose of the contract is to aim at operating all trains by green power. [22]

The contract mainly covers the following three points in the scope of this thesis. The first point is electricity price. The contract provides the almost fixed price without fluctuations by market uncertainty for 10 years. The next point is energy volume. The electricity volume of the previous year is referred to as the volume forecast of the next year.

The last point is an option. NS has an option to review or discard the contact in 2019 to avoid the risk of uncertainty or unexpected events.

The source of green power in the contract was new wind power plants in the Netherlands, Sweden and Belgium. Half of them are from the Netherlands, and the other half generate from abroad. This dispersed production outside of the Netherlands aims at not limiting the existing other renewable projects. The flexibility of infrastructure, which Figure 3.7 presents, (i.e., electricity export and import of the Netherlands) enables this strategy.

Applying the Causal Loop Diagram

Applying the circumstances stated above, Figure 3.9 shows the matured loop and ley loop for the contract of NS and Eneco.

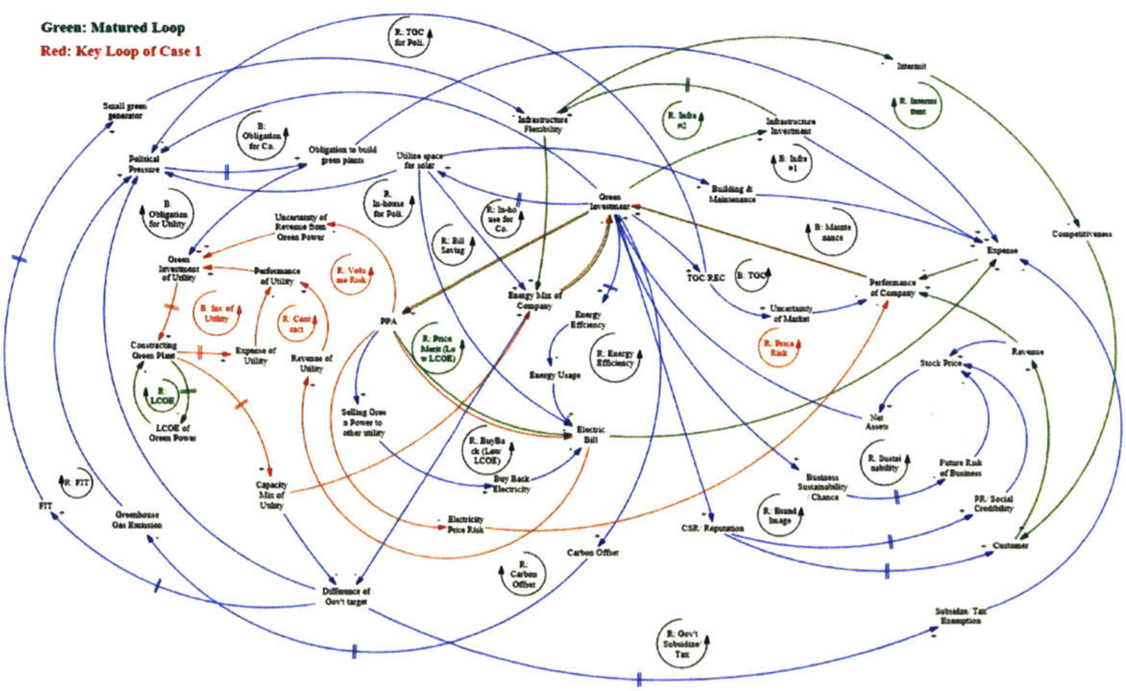


Figure 3.9: Causal Loop Diagram of Case 1 (NS and Eneco)

Green Loop: Matured for case 2, Red Loop: Key Loops for case 2

Key loops; B: Inv. of Utility

The energy mix of a utility is almost the same as that a utility can provide, because the volume of in-house generation is relatively or quite small rather than that of purchasing electricity from utility; thus, how a utility can follow the cycle of Inv. of Utility loop faster plays an important role for increasing the Capacity Mix of the Utility. In fact, the first plan of NS and Eneco targeted to complete renewable shift in 2018, but it actually completed in 2017. Thus, investment of the utility was the key factor of the project schedule management.

Key loops; R: Contract

Key loops; R: Volume Risk

Key loops; R: Price Risk

The detailed contents of the contract between NS and Eneco are the most important factors, and they can show in the three loops: Contract loop, Volume Risk loop, and Price Risk loop.

Matured loops; R: LCOE

Matured loops; R: Price Merit (Low LCOE)

The renewable LCOE of the Netherlands is cheaper than that of traditional energies, which is the price merit of this contract.

Matured loops; R: Infra #2

Matured loops; R: Intermittent

The maximum amount of energy Eneco provides is 1.4TWh, which is equivalent to only 1% of energy volume of the energy consumption of the overall Netherlands [27], and half of it is generated outside of the Netherlands, in Finland and Belgium. NS made the most use of flexible infrastructure.

Reference loops; R: Energy Saving

NS has set the energy saving target as 35% less energy by 2020 when compared to consumption in 2005. To achieve this target, NS plans to be 50% more efficient in running its trains than in 2005 by 2020. Although this strategy reduces the total amount of energy consumption, it was not very effective for the renewable shift.

3.2.2 Case 2 (Google)

Background of Case 2

Google achieved the shift to having all of the energy consumption required for is business coming from completely renewable sources in 2017. The most unique point of the energy shift at Google was the strategy. The main concept of Google is to offset their energy usage by purchasing renewable energy (i.e., Google purchased the same amount of green energy as it consumed, and Google resold the renewable energy to the local utility) [28]. Since Google does business all over the world, the difference of regulation or standard makes it difficult to consume completely renewable energy. Even if Google could achieve this in some countries, it must have a huge delay time. Thus, focusing on specific regional data such as energy portfolio or infrastructure flexibility is not appropriate, and so we only focus on the renewable shift model Google made. Google finalized their achievement as promoting the renewable energy consumption by building the new type of power purchase model, which can apply to other companies [29].

Applying the Causal Loop Diagram

Figure 3.10 shows the matured loop and key loop for the Google power purchase model.

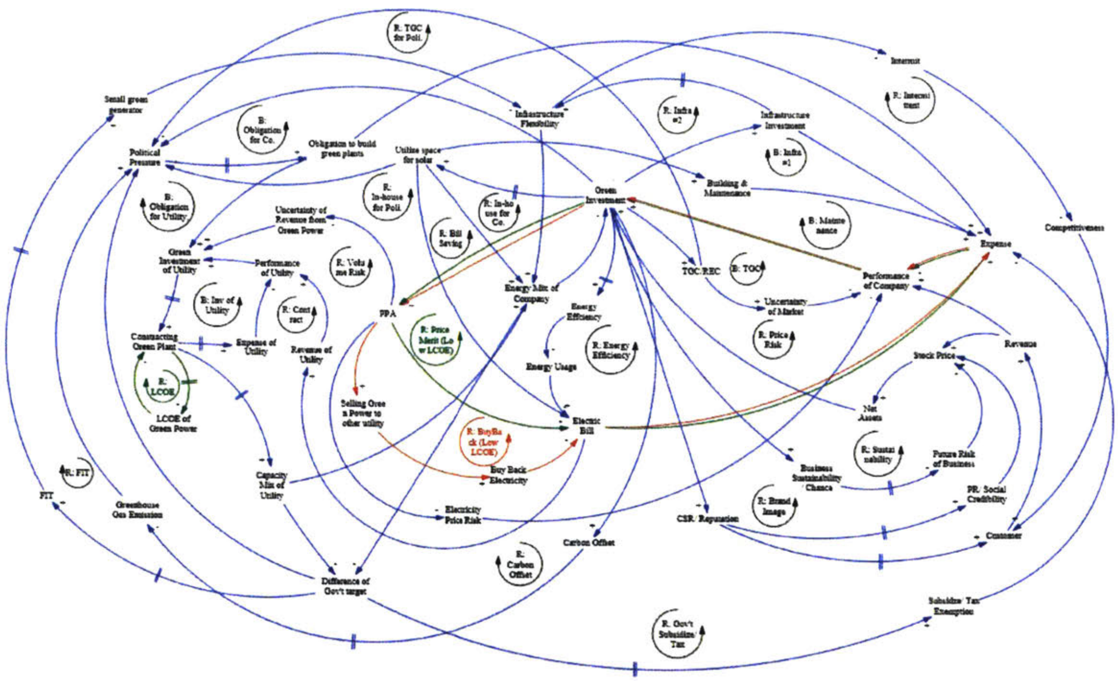


Figure 3.10: Fig 3.9 Causal Loop Diagram of Case 2 (Google)
Green Loop: Matured for case 2, Red Loop: Key Loops for case 2

Key loops; R: Buy Back (Low LCOE)

Matured loops; R: LCOE

Matured loops; R: Price Merit (Low LCOE)

As stated above, the low LCOE is one of the important factors in this case because it can be a loss for a company if the LCOE of renewables is relatively higher than the traditional energy. Under the circumstances of low LCOE, the Price Merit loop is also matured.

3.2.3 Case 3 (RICOH)

Background of Case 3

RICOH is the first company in Japan which joined RE100, and has the target that RICOH will consume only renewable energy in their factories and offices by 2050.

Energy Mix of Japan

Figure 3.11 [24] illustrates the transition of generating volume in Japan after 2005. Figure 3.12 [30] presents the detail energy portfolio in Japan in 2015. Because of the great Japan earthquake in 2011, which triggered the Fukushima nuclear power accident, the share of nuclear decreased dramatically after 2011, and thermal power is the main source of Japanese electricity. Only 3.2% of Energy is generated from renewables.

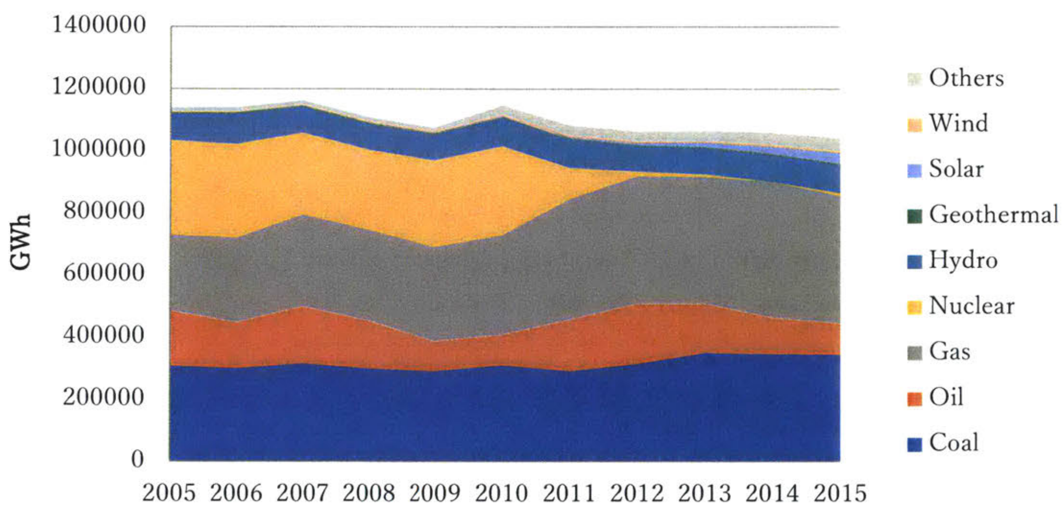


Figure 3.11: Transition of Electricity Generation in Japan

(Source: IEA)

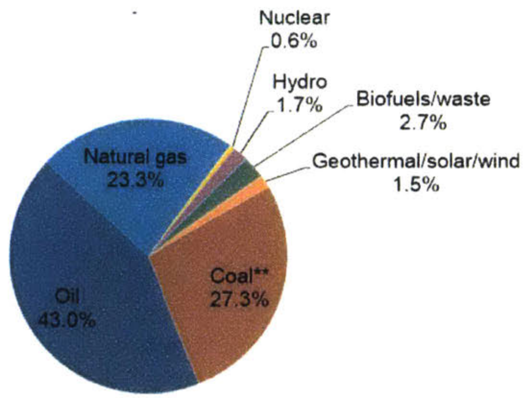


Figure 3.12: Energy Portfolio of Japan in 2015

(Source: IEA)

Generation Cost of Japan

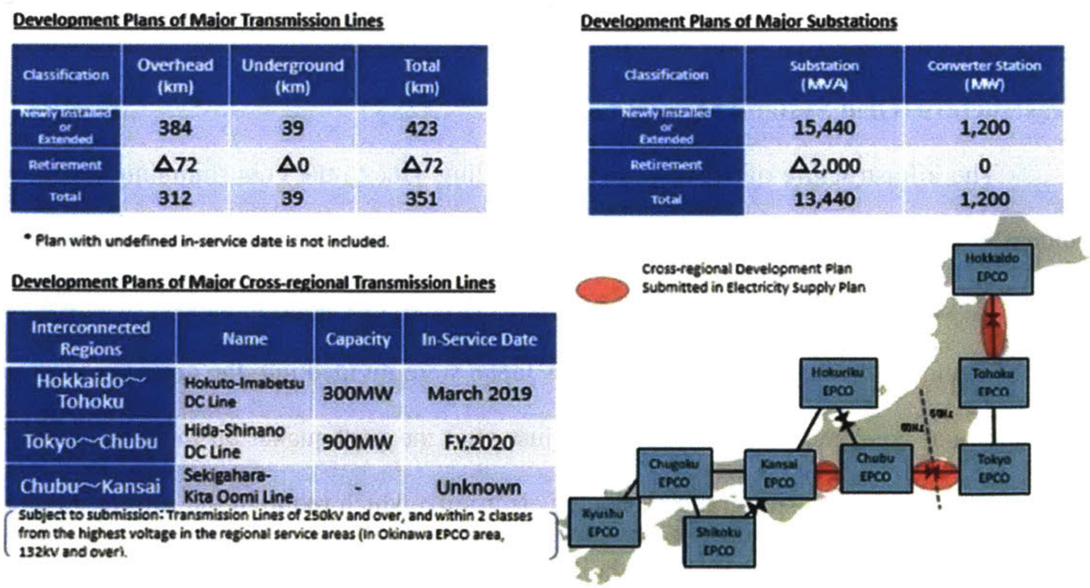
As discussed in Section 2.3.1 LCOE, the generation cost of renewable energy is more expensive than that of traditional energy in Japan. Based on the forecast of ANRE, the generation cost of solar power will be approximately that of coal, and that of wind power will be approximately that of LNG.

Infrastructure (Grid System) of Japan

The infrastructure of Japan is now remodeling. Due to the Fukushima nuclear power accident, many plants suffered and did not supply the electricity to customers. In fact, Tokyo Electric Power Company was short of its supply which was approximately 10 GWh, one fourth of demand forecast. Since the utility of Japan were divided into the area, the west part of Japan could consume electricity as usual just after the earthquake; on the other side, the east part of Japan had to stop transmission of electricity, which required the rolling outage in Tokyo in the following ten days after the earthquake. Therefore, OCCTO, Organization for Cross-regional Coordination of Transmission Operators, were established. According to the OCCTO website, OCCTO has three steps to achieve the three goals; "Securing Stable Electricity Supply, Suppressing Electricity Rates to the Maximum Extent Possible and

Expanding Choices for Consumers and Business Opportunities." The achievement of step 1 was focused on the establishment of OCCTO in April 2015. Step 2 achieved the "full liberalization of entry to electricity retail business" and "the Introduction of functional licensing system" in April 2016. Step 3 is in progress to complete "Legal unbundling of transmission/distribution sector"

Additionally, some utilities in Japan announced that they were not sure about the new acceptance of the electricity from solar power in 2014. This aims to reduce the risk that some grid system could exceed the limit of capacity. Since the grid system of Japan was not flexible to share the electricity with the next grid company, the grid connection of the grid system, the flexibility of the grid system, plays an important role for increasing the use of renewable energy. In fact, as Figure. 3.13 shows, OCCTO plans to increase the grid connection across utilities, which makes infrastructure flexible.



Development Plans of Major Transmission Lines

Classification	Overhead (km)	Underground (km)	Total (km)
Newly Installed or Extended	384	39	423
Retirement	Δ72	Δ0	Δ72
Total	312	39	351

* Plan with undefined in-service date is not included.

Development Plans of Major Substations

Classification	Substation (MVA)	Converter Station (MW)
Newly Installed or Extended	15,440	1,200
Retirement	Δ2,000	0
Total	13,440	1,200

Development Plans of Major Cross-regional Transmission Lines

Interconnected Regions	Name	Capacity	In-Service Date
Hokkaido～Tohoku	Hokuto-Imabetsu DC Line	300MW	March 2019
Tokyo～Chubu	Hida-Shinano DC Line	900MW	F.Y.2020
Chubu～Kansai	Sekigahara-Kita Oomi Line	-	Unknown

Subject to submission: Transmission Lines of 250kV and over, and within 2 classes from the highest voltage in the regional service areas (In Okinawa EPCO area, 132kV and over).

Figure 3.13: Projection of the Network Development Plan up to F.Y.2025

(Source: OCCTO)

Strategies of RICOH

RICOH set the five goals for social issues on April 27, 2017 [32]. Also, RICOH joined RE100 at the same time. The two goals of five are "Zero-carbon Society" and "Circular Economy." In detail of this goal, RICOH has committed to using a minimum of 30% renewable energy by 2030 and 100% by 2050.

RICOH has three concrete strategies to achieve their goals [33]. The first strategy is to stimulate the innovation of the renewable supply system including government policy. The second strategy to make the best effort to reduce carbon emission by RICOH themselves, not only constructing the green power inside of their space, but reducing energy by the improvement of manufacturing process. The third strategy is not purchasing the TGC (Traceable Green Certificate) or the replacement of purchasing electricity before achieving thorough energy saving.

Applying the Causal Loop Diagram

RICOH strategy CLD as of 2018

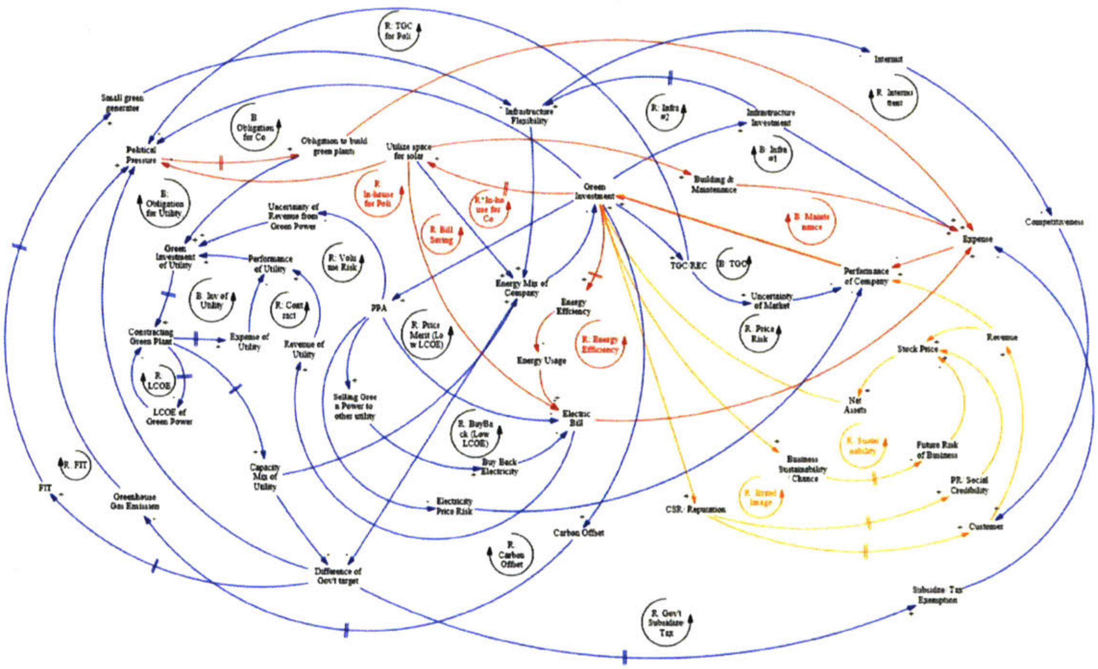


Figure 3.14: Causal Loop Diagram of Case 3 (RICOH) as of 2018

Green Loop: Matured Loops for case 2, Red Loop: Key Loops for case 2

Orange Loop: Motivation Loops for renewable shift

Key loop; R: Energy Efficiency

Key loop; R: In-house for Co.

Based on the strategies of RICOH, this loop plays an important role as of now.

Key loop; B: Maintenance

Although this loop is not mentioned, building a new renewable farm requires their maintenance; thus, this loop is a key loop.

Key loop; In-house for Poli.

Key loop; Bill Saving

These loops are the secondary effect of building in-house generators, but the saving effect of electricity bill and reducing the political pressures are necessary factors to judge the investment of building a new farm.

Motivation loop: R: Brand Image

Motivation loop: R: Sustainability

According to the RICOH website, "Ricoh aims to create new markets and value propositions by looking broadly at social issues, and taking on the challenge to resolve them while simultaneously achieving social development and Ricoh's own business growth." [32] New markets for RICOH increase their sustainability, and resolving the social challenge increases the reputation of RICOH.

RICOH strategy CLD of step 2

Based on the RICOH interview, after establishing saving energy, RICOH will move to the next step to purchase TGC. The balancing loop of "TGC" and reinforcing loop of "TGC for Poli." are the key loops of step 2.

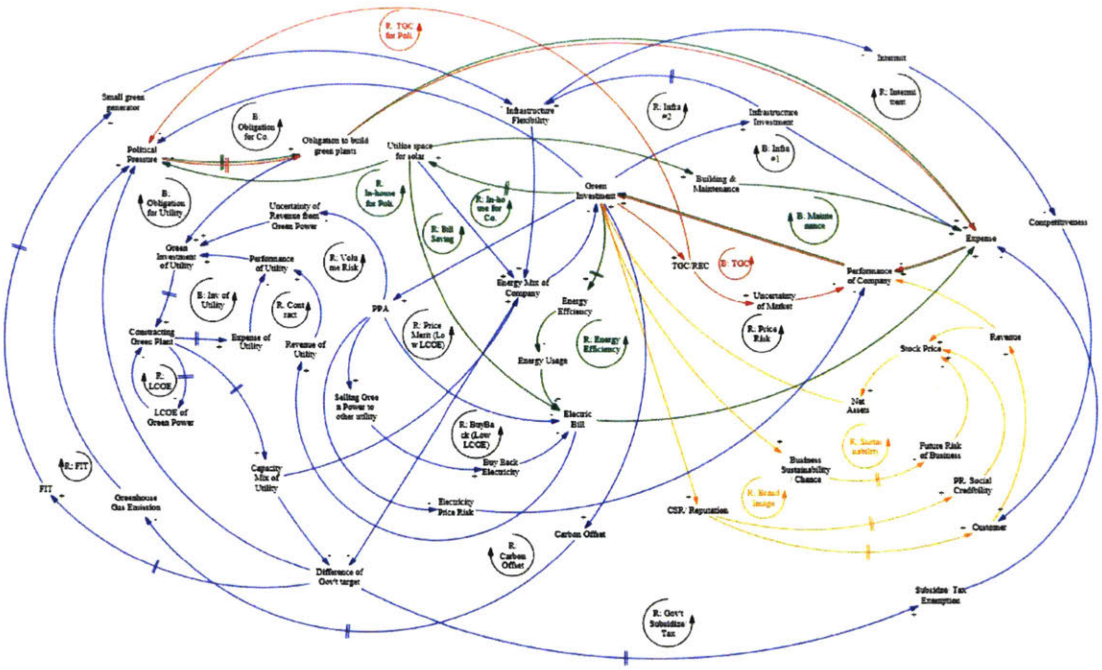


Figure 3.15: Causal Loop Diagram of Case 3 (RICOH) in step 2

Green Loop: Matured Loops for case 2, Red Loop: Key Loops for case 2,

Orange Loop: Motivation Loops for renewable shift

RICOH strategy CLD of step 3

RICOH will move to step 3 after TGC matured if the generation cost of renewables is decreased and the flexibility of infrastructure is increased. These are the first strategy of the RICOH interview. Thus, the reinforcing loops of "LCOE" and "Infra#2" are the required loops. Also, the reinforcing loops of "Contract," "Volume Risk" and the balancing loop of "Inv. of Utility" are the key loops.

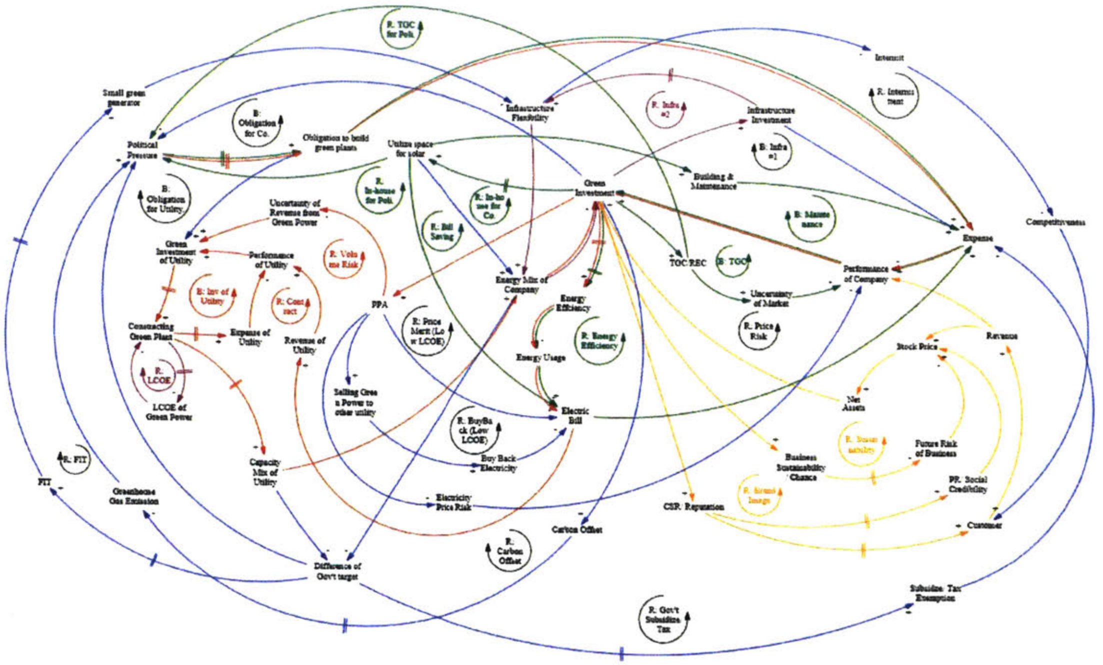


Figure 3.16: Causal Loop Diagram of Case 3 (RICOH) in step 3

Green Loop: Matured Loops for case 2, Red Loop: Key Loops for case 2,

Orange Loop: Motivation Loops for renewable shift,

Purple Loop: Requirement Loops to start step 3

3.3 Conclusion

Through analyzing three cases, the renewable shift can be divided into three phases. The first step, phase 1, aims at the "kick off" of the energy shift mainly by governments, preparing the important factors of an energy shift ecosystem, whose purpose is to reduce the renewable energy cost and to build the system which makes companies change energy source from non-renewable to renewable. The characteristic of the second step, phase 2, initiates the renewable shift by private sectors in terms of economic decisions. The purpose of the third step, phase 3, is to push forward by public sectors to achieve the government targets. The last step may not need if economic benefit of energy shift is strong.

Although each country has the different strategies, key factors of each phase are summarized in Table 3.1. Also, the key loops of each phase are described as Figure 3.17.

Table 3.1: Key Factors and the Responsibility for Each Phase

Phase	Key Factor/ Loops	Responsibility
1	Low LCOE	Public and Private
	FIT	Public Sector
	TGC/REC	Private Sector
	In-house renewable plant	Private Sector
	Saving Energy Strategies/ Technologies	Private Sector
	Motivation for using renewables (Planning)	Private Sector
	Carbon Offset	Private Sector
2	Flexible transmission by matured grid system	Infrastructure
	Power Purchase Agreement	Private Sector
	New construction of renewables	Utility
	Buy Back	
	Motivation for using renewables (Executing)	Private Sector
3	Subsidize/ Tax exemptions	Public Sector
	Obligations to companies and utility	Public Sector

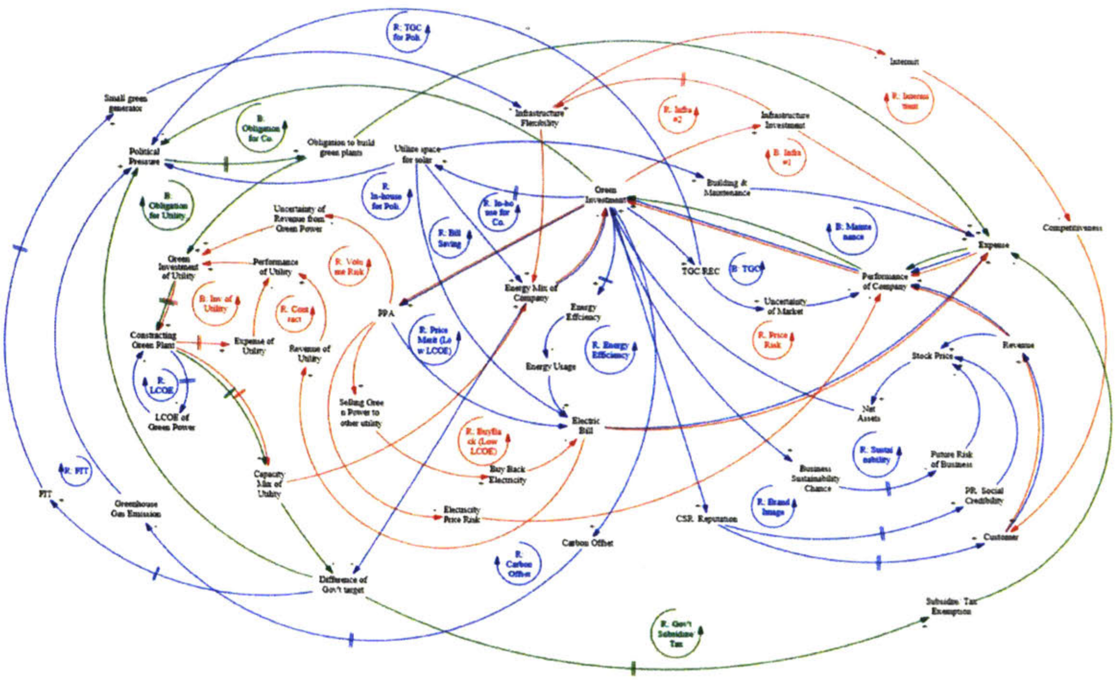


Figure 3.17: Key loops of each phase.

Blue Loops: Key Loops for phase 1, Red Loops: Key Loops for phase 2,

Green Loop: Key loops for phase 3,

Considering the Phase of Each case

Case 1 starts from phase 2 and is completed without phase 3, because this project is based on the electricity import from other countries, which indicates that a flexible infrastructure exists. Also, the generation cost of renewables is also inexpensive rather than the traditional energy. Thus, the starting point of case 1 is phase 2. This project is completed without government obligation and pressure, so this project ends in phase 2.

Case 2 starts from phase 2 and is completed without phase 3, because this project is based on the low generation cost of renewables and does not care about the infrastructure. Thus, the starting point of case 2 is phase 2. This project is completed without government obligation and pressure, so this project ends in phase 2.

Case 3 starts from phase 1 and will end in phase 3. The infrastructure of Japan is now reorganizing to reinforce the grid connection, and the generation cost of renewables in Japan is more expensive than it is for traditional energy. Based on the forecast of Japanese political part, renewables will be inexpensive as well as some traditional energy in 2030. Considering the flexibility construction, around 2030 is the transitional point from phase 2 to phase 3. RICOH also mentioned that RICOH will stimulate the renewable ecosystem in Japan including government. Thus, subsidies and tax exemptions should be taken into account in case 3. As a result, case 3 will complete in phase 3.

Chapter 4 Stock and Flow Analysis

4.1 Model Building

Overall stock and flow model is shown in Figure 4.1. This model consists of two subparts: the company part and the utility part.

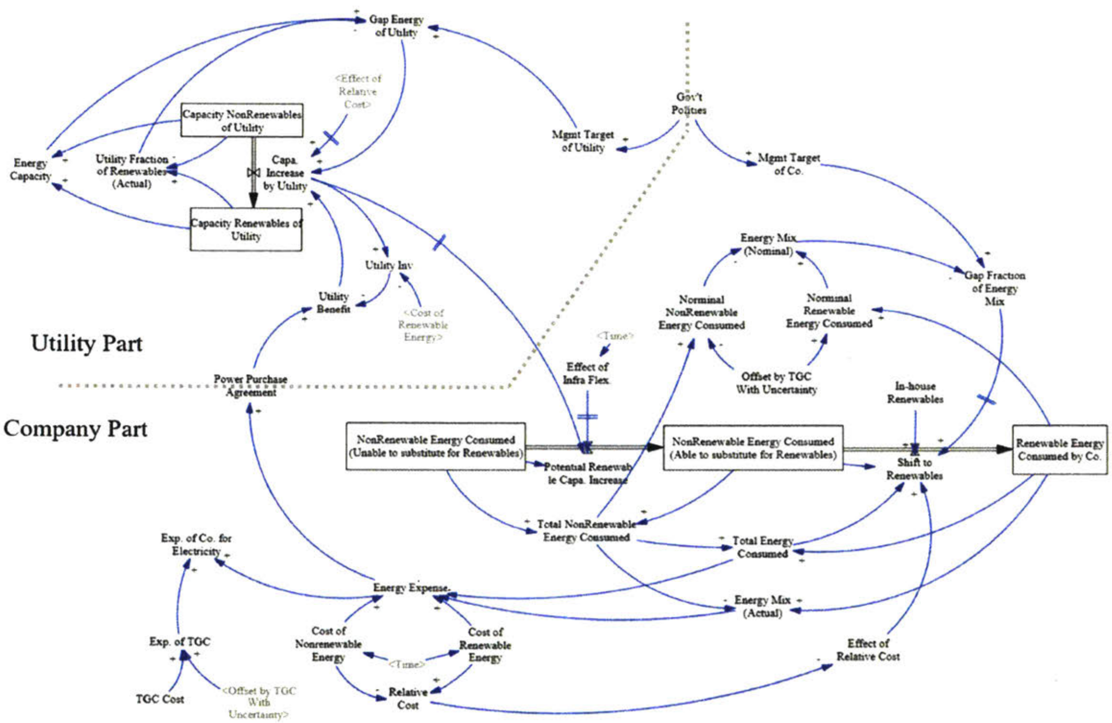


Figure 4.1: Stock and Flow Model

Assumptions

This model contains the assumptions as below.

1. No energy shift from renewable to non-renewable occurs.
2. Company and Utility follow the government policy and will not change their strategies that they published as of March 2018.
3. Company and Utility do not leave the gap between their targets and results.
4. Electricity volume utility supplies do not change.

Company Part

A key point in this model of the company part is to divide the energy consumption into three factors: "Renewable Energy Consumed by Co," "NonRenewable Energy Consumed (Able to substitute for Renewables)" and "NonRenewable Energy Consumed (Unable to substitute for Renewables)." The first part simply shows the consumption of renewable energy. The second part is the part of the energy consumption of non-renewables, but that can be substitute for renewables by the decision of company. The third part is the rest of non-renewable energy consumption, which must not be replaced by renewables. The transition flow from the second part to the first part is "Shift to Renewables," and that from the third to the second is "Potential Renewable Capa. Increase."

The only factor of deciding "Shift to renewables" is the decision of the company, and two compositions of "Shift to renewables" exist: the gap between management target of company and nominal energy mix, and "In-house Renewables." The management target of a company takes the government policy into account to avoid the obligation or being imposed extra tax. The gap of target and result is calculated as "Gap Fraction of Energy Mix" times "Total Energy Consumed." The relative cost of renewables and non-renewables are the factor of the company judgement (i.e. if renewable cost is cheaper than non-renewable cost, companies decide to consume renewable instead of non-renewable.).

"Potential Renewable Capa. Increase" is measured by the renewable capacity of the utility, which is defined as "Capa. Increase by Utility" and the flexibility of infrastructure. Increasing renewable capacity is not sufficient because energy should transmit by grid system. "Effect of Infra Flex." has a delay because constructing and connecting to the existing system requires some duration to start its operation.

The nominal Energy Mix is the most appropriate criterion of evaluating the energy mix of a company because this factor considers the actual results of energy consumption and the trade of renewable values in market. After consuming the energy, TGC can offset the usage of non-renewable. Thus, "Nominal NonRenewable Energy Consumed" is calculated as "Total NonRenewable Energy Consumed" minus "Offset by TGC." Also, "Nominal Renewable Energy Consumed" is calculated as "Total Renewable Energy Consumed" plus "Offset by TGC."

The energy expense of company is described below and should be the same amount as the utility revenue of a company.

$$\begin{aligned} &Energy\ Enpense \\ &\quad = Total\ Energy\ Consumed \times Actual\ Energy\ Mix \times Cost\ of\ Renewable\ Energy \\ &\quad + Total\ Energy\ Consumed \times (1 - Actual\ Energy\ Mix) \\ &\quad \times Cost\ of\ Non\ Renewable\ Energy \end{aligned}$$

In this model, the electric bill is regarded as the revenue of power purchase agreement of a company. The total expense of company for electricity is described as adding the TGC cost to energy expense. The expense for TGC is calculated as TGC cost times the offset volume of TGC with market risk.

Utility Part

The utility supplies the two types of energy: renewable and non-renewable. Transition from non-renewable to renewable is defined as "Capa. Increase by Utility," which is the same as the gap between the renewable volume target of the utility and its actual volume if the utility can earn the benefit from this project (i.e. the revenue of a company exceeds the investment of utility for this project) and the relative cost of renewable is cheaper than that of the non-renewable. The management target of the utility also considers the government policy or target. Utility benefit is calculated as the revenue of power purchase agreement minus the cost of investment for this project, which is the capacity volume increase times cost of renewable energy.

4.2 Base Case Analysis

In this thesis, the following study in Section 4.2 Base Case Analysis and Section 4.3 Sensitivity Analysis is focused on the renewable shift in a Japanese company. Since ROCOH had some strategies for the renewable shift when they joined RE100, these strategies are included for these analyses. The parameters of the Base Case Analysis are as below.

Company Part

Management Target of Co

Based on the targets of RICOH, some milestones are applied to this model in Table 4.1. Thus, these two milestones are the input of the base case analysis of the company part. In this base case analysis, the target of each year is simplified to the linear.

Table 4.1: Milestones of RICOH and ASKL

Milestone	By	Target of energy mix
Mid-term	2030	At least 30%
Long-term	2050	100%

Offset by TGC with Uncertainty

Based on the strategy of RICOH, which is stated in Chapter 3.2.3, RICOH will deal with TGC after their saving strategy is established. Thus, the scenario of TGC trading is below.

- Purchasing 500MWh of TGC every year after 2025 (5% of total energy consumption)
- Contains 10% of uncertainty

- Cost of TGC is the same as 2018 (i.e. if 5years contract, the unit price is 6.5kWh)

In-house Renewables

In Japan, setting solar panels on the roof is the popular way to increase In-house renewables. In the base case, the 500kWh of solar panel are assumed to be built in 2020, 2025 and 2030.

Non-Renewable Energy Consumed and Renewable Energy Consumed

In the base case, the following assumptions are reflected in the input.

- Total energy consumption is 100,000MWh.
- The initial input of renewable energy consumption is 9,000MWh. (The energy mix in Japan was 9% in 2015.)
- 10% of non-renewable energy consumption can be replaced by renewable in 2015.

Effect of Infra Flex.

Increasing flexibility from 2015 to 2020, half of the renewable energy is assumed to be restricted for supplying in 2015, but there is no restriction by infrastructure in 2020. This numeric input is based on the strategy of the Ministry of Environment [34], which states utilizing the smart grid technology for using the large scale of renewable energy by 2020 as their mid-term goal.

Cost of Renewable Energy and Cost of Non-Renewable Energy

The energy cost is calculated as below.

$$Cost\ of\ Renewable\ Energy$$
$$= \sum (LCOE\ of\ Renewable\ Source \times its\ Proportion\ of\ Renewables)$$

For example, a renewable energy consumption of Company A assumes to divide into 30% solar and 70% wind. Also, the LCOE of solar assumes 15yen/kWh and the LCOE of wind assumes 14yen/kWh. The cost of renewable energy is calculated as below.

$$Cost\ of\ Renewable\ Energy\ of\ Company\ A = 15 \times 0.7 + 14 \times 0.3$$

The cost of non-renewables can be defined as the same way.

$$Cost\ of\ Non\ Renewable\ Energy$$
$$= \sum (LCOE\ of\ Non\ Renewable\ Source$$
$$\times its\ Proportion\ of\ Non\ Renewables)$$

In this paper, the following assumption is included due to the fluctuation of energy mix in Japan since the Fukushima nuclear power plant accident. As Figure 4.2 illustrates, the Japanese energy mix shifted not to consume energy from nuclear power after 2011. However, this shift was not based on a long-term strategy. Thus, under the assumption that the energy mix of Japan will converge to the target based on the forecast published by ANRE, the cost of renewable energy and non-renewable energy is calculated based on the energy mix of 2030.

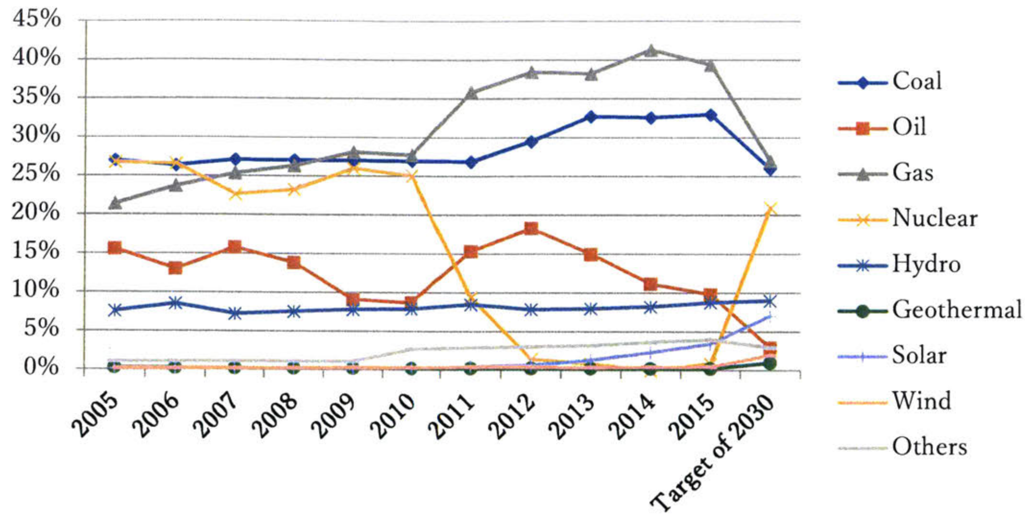


Figure 4.2: Transition of Energy Mix in Japan and its Target for 2030

Note: Data after 2011 affected by Fukushima Nuclear Power Plant Accident

Effect of Relative Cost

Effect of Relative cost compensates for the catching up time for the renewable shift with delay (i.e. a company cannot switch from non-renewable to renewable suddenly).

Utility Part

Management Target of Utility

Since the Energy Mix of company is affected by the target of the Utility, a company and utility negotiate to build the plan for energy shift. In this paper, the target of the utility is assumed the double pace as the target of a company not to prevent from the renewable shift of a company.

Others

Gov't Policy

The government policy should be dealt with as a "check point" of the energy mix of company. Thus, the input of government policy is the step function, which is 9% by 2030 (the results of energy mix in 2015) and 20% after 2030 (the political target based on the Paris Agreement, mentioned in Section 2.1.2).

4.3 Sensitivity Analysis

Based on the forecast of ANRE of the cost of renewable energy and non-renewable energy in 2014 and 2030 (stated in Section 2.3.1), three types of future cost are assumed from 2015 to 2030. Since the results of FY2014 were quite similar to the starting cost of 2015, the following sensitivity analysis is simulated from 2015 to 2030. The base case is the S curve, and the second case is decreasing quickly from 2015. The third case is decreasing moderately at first and quickly near 2025. After 2030, no cost forecast of Japanese cost is published. Thus, this model is applied from 2015 to 2030. Figure 4.3 illustrates the sensitivity inputs of "Cost of Nonrenewable Energy" and "Cost of Renewable Energy."

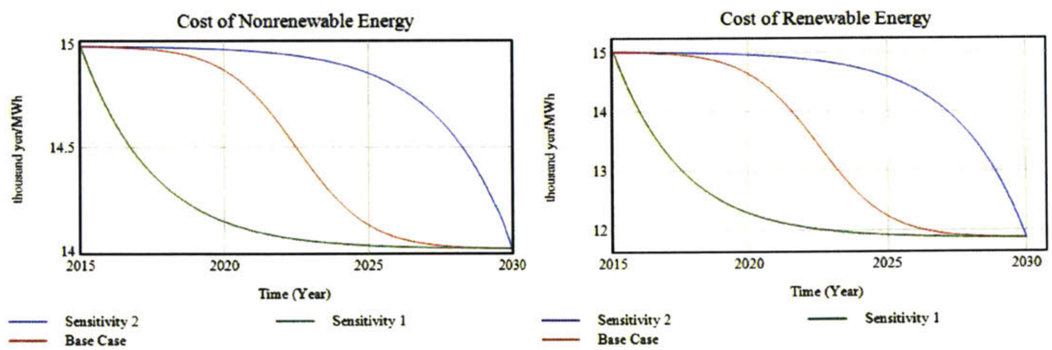


Figure 4.3: Cost of Non-Renewables and Renewables for Sensitivity Analysis

4.4 Results and Future Work

Results

Relative Cost

Based on the inputs identified in Figure 4.3, Figure 4.4 shows the results of "Relative Cost." All three curves start from positive and move down to negative, but the timing differs when they change from positive to negative. The reversal point with delay is presented in "Effect of Relative Cost" which is the right part of Figure. 4.4. The reversal points occur in 2017 in the Base Case, 2015 in Sensitivity 1, and 2020 in Sensitivity 2.

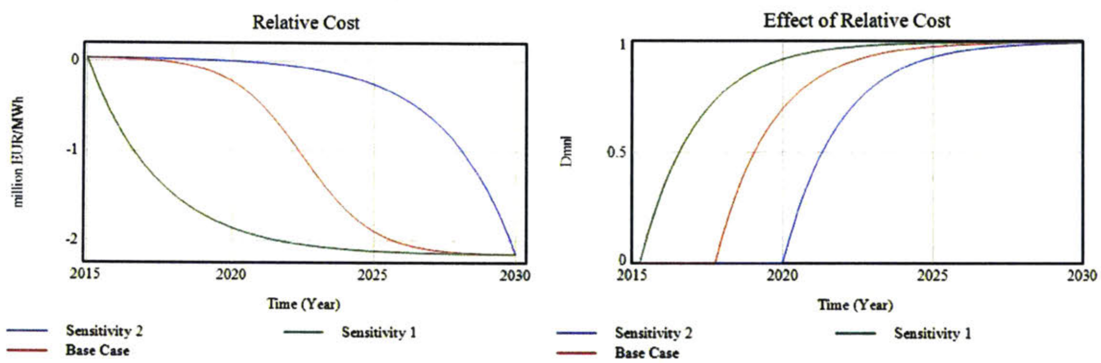


Figure 4.4: Relative Cost

(Left: Overall behavior from 2015 to 2030, Right: Effect of Relative Cost)

Potential Renewable Capacity Increase

The "Potential Renewable Capa. Increase" is illustrated in Figure 4.5. From 2015 to 2025, three cases have their own peaks. After that, three cases converge to the same point, 3000MWh/Year. As the rise times of "Potential Renewable Capa Increase" are late, the peaks of three curves tends to be higher.

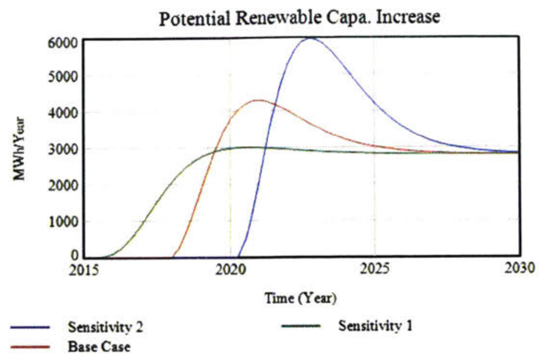


Figure 4.5: Potential Renewable Capa. Increase

The results of "NonRenewable Energy Consumed (Unable to substitute for Renewables)" and "NonRenewable Energy Consumed (Able to substitute for Renewables)" are summarized in Figure 4.6. The differences of three cases mentioned above from 2017 to 2025 are also shown in both graphs in Figure 4.6 (especially, right graph). After 2025, the "Shift to renewables" is the reason of the dynamics of "NonRenewable Energy Consumed (Able to substitute for Renewables)."

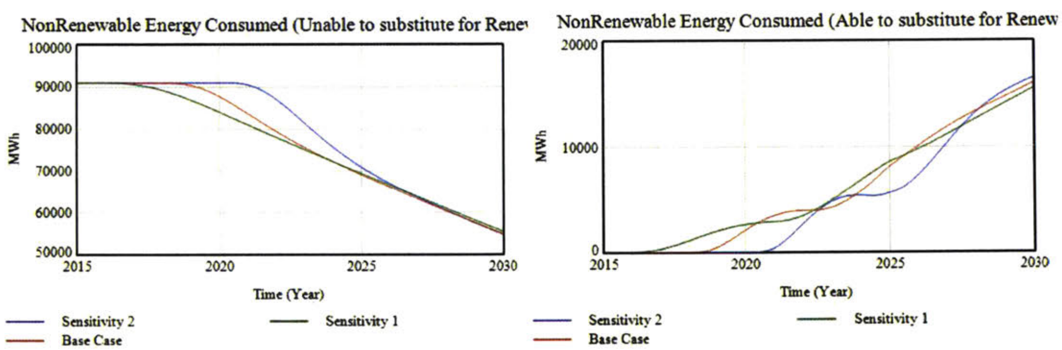


Figure 4.6: Results of Non-Renewable Consumption: Unable to Substitute, and Able to Substitute

Shift to Renewables

The "Shift to Renewables" and "Renewable Energy Consumed by Co" are illustrated in Figure 4.7. The former part of the dynamics of "Shift to Renewables" is a result of the "Effect of Relative Cost." Figure 4.8 shows when the "Gap Fraction of Energy Mix" turns to the negative (i.e. when the "Energy Mix (Actual)" exceeds the "Mgmt Target of Co."). The gap of the Base Case and Sensitivity 1 case stays positive by 2030. However, the gap of the Sensitivity 2 from 2026 to 2028 is negative. This difference results in the stagnation of "Renewable Energy Consumed by Co." As the rise times of "Shift to Renewables" are late, the peaks of the three curves are also higher.

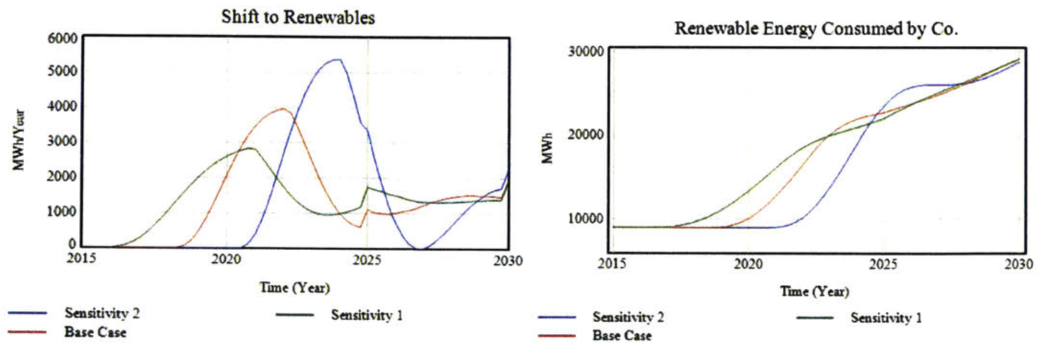


Figure 4.7: Shift to Renewables

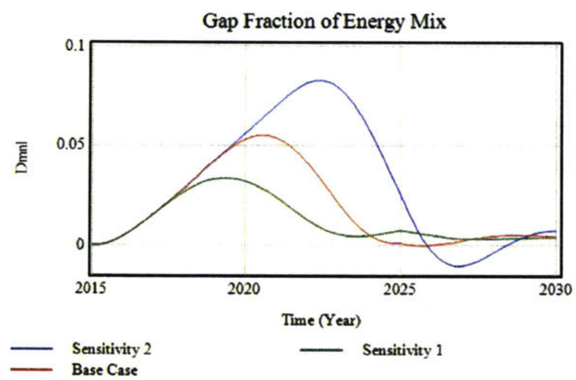


Figure 4.8: Gap Fraction of Energy Mix

Management Target and Energy Mix

The management target of the company is followed by Table 4.1, which is illustrated in Figure 4.9 below. All three simulations have the same company target, but the "Energy Mix (Actual)" including the TGC trading has different behaviors.

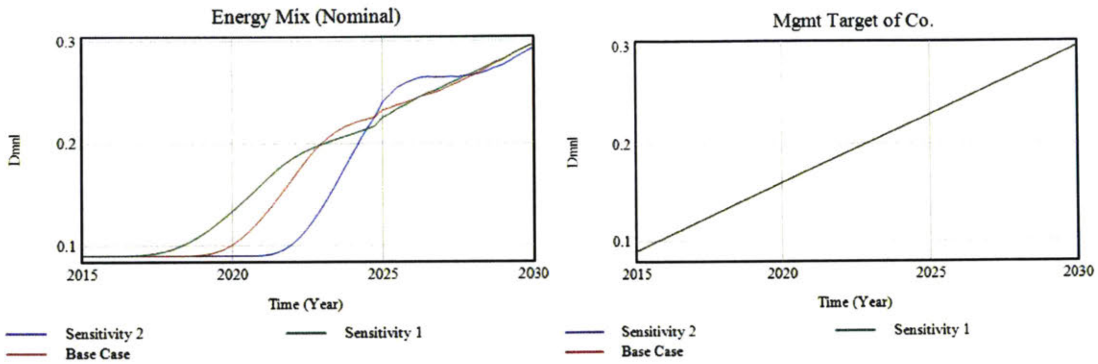
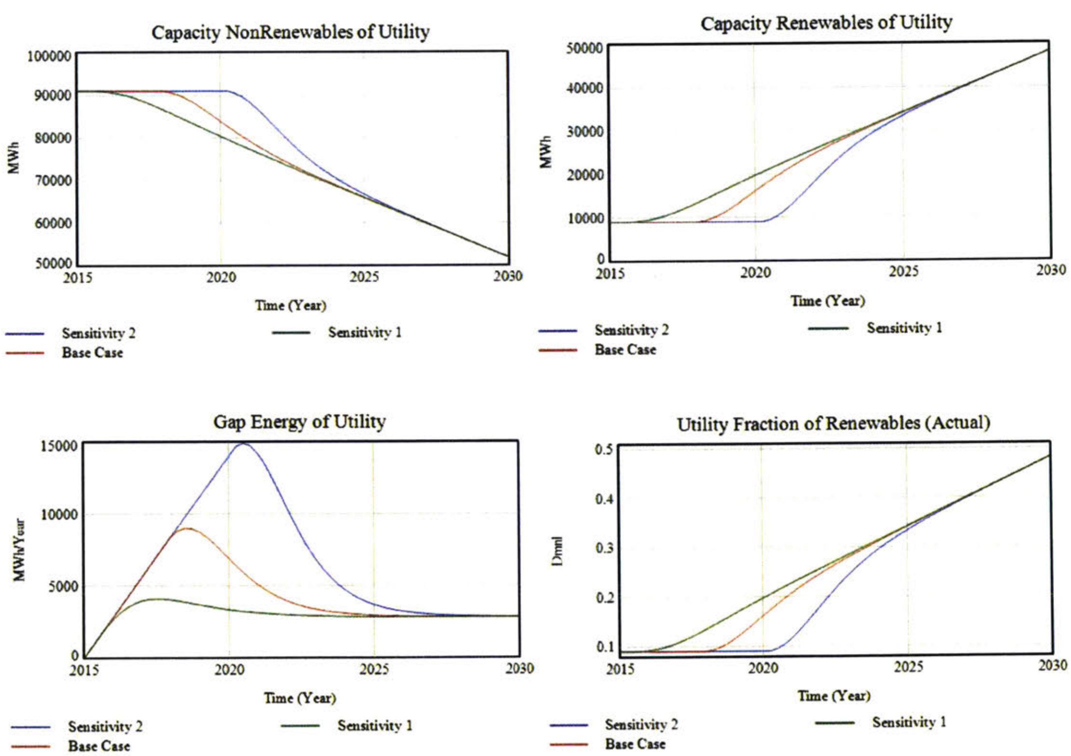


Figure 4.9: Energy Mix of Management Target of Company

Other Results

Other results are summarized in Figure. 4.10 below.



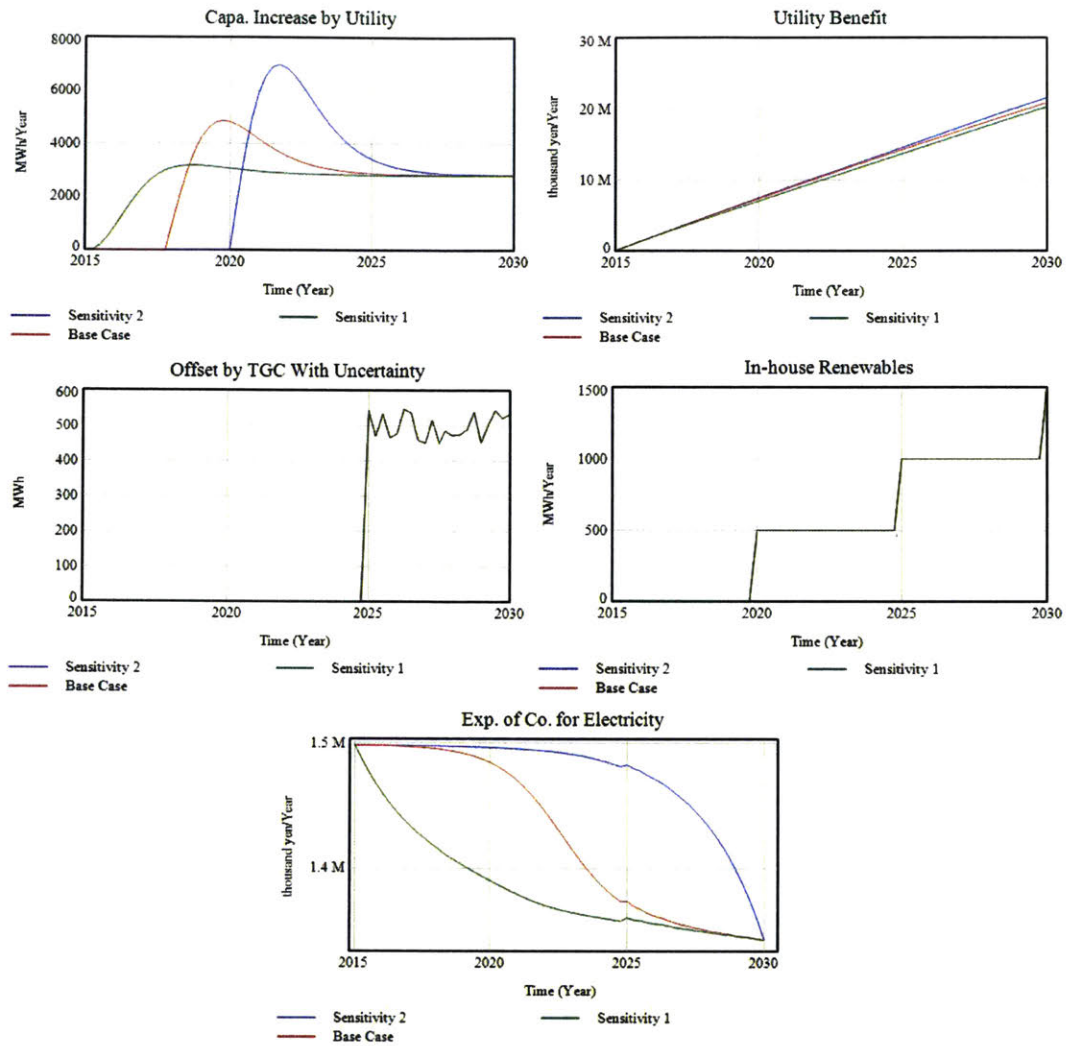


Figure 4.10: Miscellaneous Results of Sensitivity Analysis

Future Work

The simulation above suggests the need for the future work below.

- Revise the Target of a company according to the utility investment.
- Apply energy mix after the confusion of Fukushima nuclear power accident.
- Revise the flexibility of infrastructure after reforming the utility in 2020 based on OCCTO data.

4.5 Conclusion

Relative Cost Triggers Renewable Shift

As the right part of Figure 4.11 presents, the "Potential Renewable Capa Increase" occurs just after renewables have more advantages than non-renewables. However, since the target of 2030 is the same for each case, the renewable shift accelerates if only a short duration remains for 2030 when the reversal point occurs.

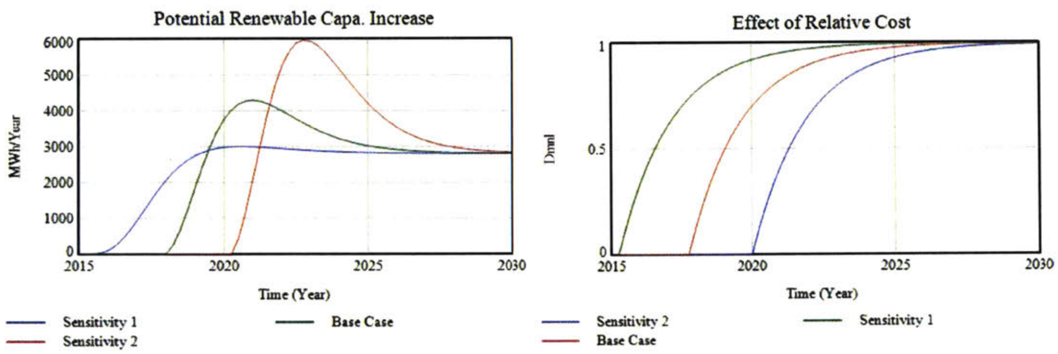


Figure 4.11: Enlarged Relative Cost and Potential Renewable Capa. Increase

External Factors of the Renewable shift Contains a Risk for a Company: Late Start of the Renewable Shift Requires the Intensive Investment

Both the "Potential Renewable Capa Increase" and "Shift to Renewables" have the same trend: As the rise times are late, the peaks of the three curves are also higher. This is because the "Gap Fraction of Energy Mix" (i.e. pressure to meet the demand) increases due to the late start of the renewable shift. Since the target is the same for the three cases, the peak of the later start case is higher. This graph shows the intensive investment required for a company if the renewable shift starts late. However, the relative cost is the external factor for a company. As a result, the external factor contains a risk for a company.

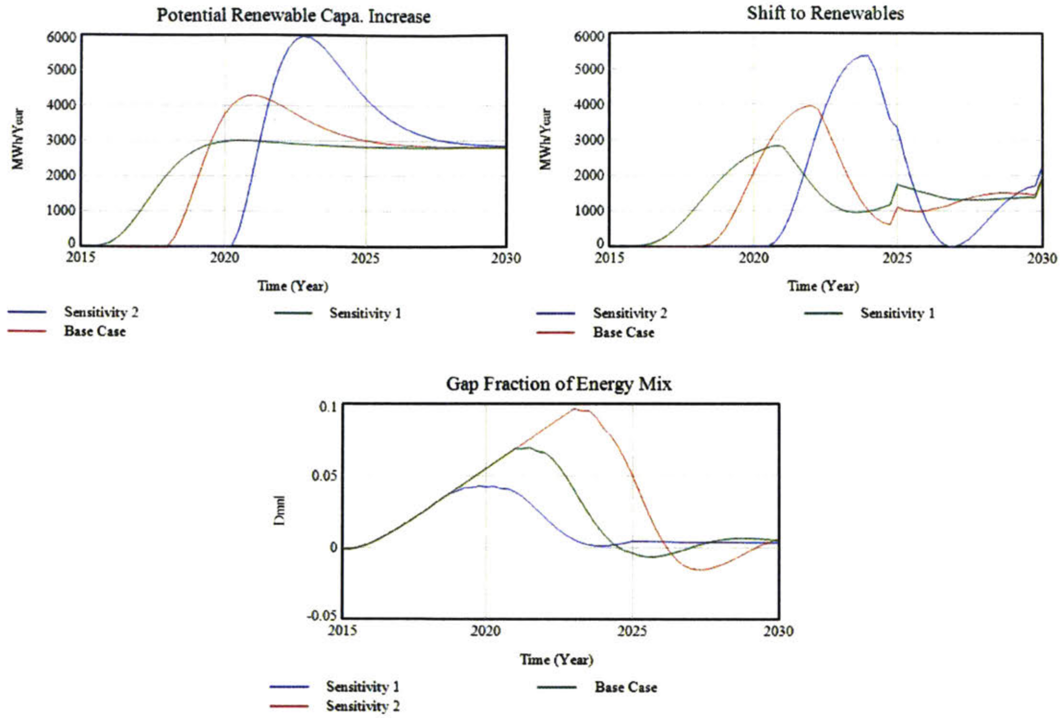


Figure 4.12: Relationships of Late Renewable Shift Starts and the Intensiveness of Dynamics

Capacity Mix of Utility Decides the Drive (acceleration/Slow Down) of Energy Mix

Three years after 2027, the "Energy Mix (Nominal)" is stable because the "Gap Fraction of Energy Mix" is negative (i.e. "Energy Mix (Nominal)" exceeds the "Mgmt Target of Co.") The main factor of this result is the fast pace of "Mgmt Target of Co." which inputs the double of "Mgmt Target of Co." Thus, the utility investment heavily affects the energy mix of a company. In fact, the energy shift of NS was completed due to the earlier construction of a wind farm by Eneco discussed in Section 3.2.1. Thus, revising the company target is included for the future work.

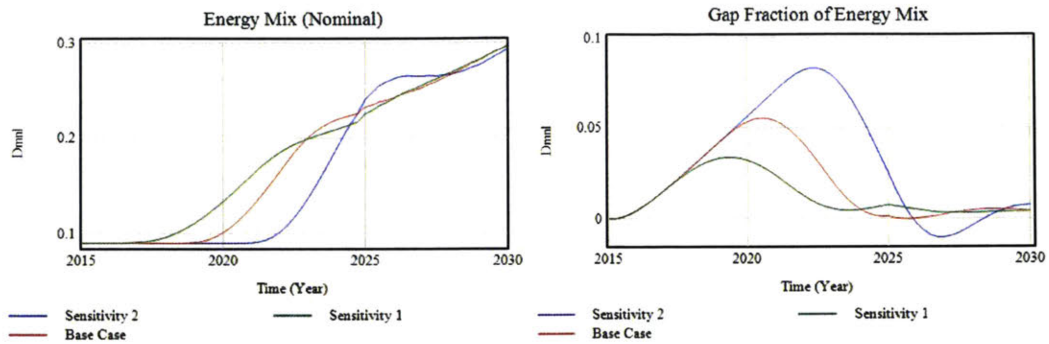


Figure 4.13: Comparison of Energy Mix (Nominal) and Gap Fraction of Energy Mix

Chapter 5 Conclusion, Findings

This chapter summarizes the key findings in this paper as follows.

- **Renewable shift can break down three phases**

Although several ways seem to be effective for increasing the consumption of renewable energy, some strategies require other conditions. Considering the whole dynamics of the renewable shift, three phases are defined. Phase 1 prepares the ecosystem for the renewable shift. Phase 2 accelerates the renewable shift by private investment based on economic benefit. Phase 3 meets the political target by public subsidies or obligation.

- **Low generation cost of renewables requires both political framework and private investment.**

Low generation cost of renewables VERB? the large amount of demand of renewables which is the investment from the private sector. However, the trigger of investment from the private sector is the cost effectiveness of renewables. Thus, establishing the political support is required.

- **Relative cost of renewables and non-renewables is not just the trigger for renewable shift, but requires the intensive investment for a company**

The target of a company includes several factors in terms of both their own business strategies and political climate; thus, it is difficult to reset the target easily. However, replacing nonrenewable with renewable energy is also difficult if the traditional energy is cost effective. Thus, companies have nothing to invest intensively to meet their target. In some cases such as Japan, publishing the company target for renewable shift may be the risk where the requirement of renewable shift is immature (i.e. phase1),

- **Capacity mix of utility can decide the drive of renewable shift**

The consumption of renewable energy can increase on the condition of enough renewable capacity from the utility. The simulation of this paper points out not only the acceleration (increasing of 2015-2027) but also slow down (stagnation of 2027-2030) of the renewable shift. In general, since the renewable shift is the cooperative project with a company and utility, the simulation of this paper does not consider that the target of a company exceeds the target of a utility.

- **Increasing the flexible infrastructure (grid system) is the key all over the world.**

Casual Loop Diagram and Stock and Flow model analysis point out the importance of the flexibility of infrastructure. In fact, not only Japan but also Europe have plans for the investment in their grid system. Based on the analysis of this paper, Europe would invest to increase the grid system to prevent from the decrease of flexibility of infrastructure due to the future increase of the renewable energy

Appendix A: Source Code of Stock and Flow Model

(01) "Capa. Increase by Utility"=

IF THEN ELSE(Utility Benefit>0, Effect of Relative Cost*Gap Energy of Utility ,0)

Units: MWh/Year

(02) Capacity NonRenewables of Utility= INTEG (

-"Capa. Increase by Utility",

91000)

Units: MWh

(03) Capacity Renewables of Utility= INTEG (

"Capa. Increase by Utility",

9000)

Units: MWh

(04) Cost of Renewable Energy: See the "Sensitivity Analysis Input" which is latter part of Appendix A

(05) "Effect of Infra Flex."=

1/(1+exp(-(Time-2015)))

Units: Dmnl

(06) Energy Capacity=

Capacity NonRenewables of Utility+Capacity Renewables of Utility

Units: MWh

(07) "Exp. of TGC"=

Offset by TGC With Uncertainty*TGC Cost

Units: yen/Year

(08) Cost of Nonrenewable Energy: See the "Sensitivity Analysis Input" which is latter part of Appendix A

(09) Effect of Relative Cost=

DELAY1(IF THEN ELSE(Relative Cost<0, 1 , 0), 2)

Units: fraction

(10) Energy Expense=

Total Energy Consumed*"Energy Mix (Actual)"*Cost of Renewable Energy+Total Energy Consumed

*(1-"Energy Mix (Actual)")*Cost of Nonrenewable Energy

Units: thousand yen/Year

(11) "Energy Mix (Actual)"=

"Renewable Energy Consumed by Co."/("Renewable Energy Consumed by Co."+Total NonRenewable Energy Consumed

)

Units: MWh

(12) "Energy Mix (Nominal)"=

MIN(Norminal Renewable Energy Consumed/(Norminal Renewable Energy Consumed

+Norminal NonRenewable Energy Consumed),1)

Units: fraction

(13) "Exp. of Co. for Electricity"=

Energy Expense+"Exp. of TGC"

Units: thousand yen/Year

(14) FINAL TIME = 2030

Units: Year

The final time for the simulation.

(15) Gap Energy of Utility=

(Mgmt Target of Utility-"Utility Fraction of Renewables (Actual)")*Energy Capacity

Units: MWh/Year

(16) Gap Fraction of Energy Mix=

DELAY1("Mgmt Target of Co."-"Energy Mix (Nominal)", 1

)

Units: fraction

(17) Gov't Polities=

STEP(0.09,2015)+STEP(0.11,2030)

Units: fraction

(18) "In-house Renewables"=

STEP(500,2020)+STEP(500,2025)+STEP(500,2030)

Units: MWh/Year

(19) INITIAL TIME = 2015

Units: Year

The initial time for the simulation.

(20) "Mgmt Target of Co."=

MAX(0.09+RAMP(0.014, 2015 , 2030)+RAMP(0.035, 2030 , 2050), Gov't Polities

)

Units: fraction

(21) Mgmt Target of Utility=

MIN(MAX(0.09+RAMP(0.028, 2015 , 2030)+RAMP(0.07, 2030 , 2050), Gov't

Polities

), 1)

Units: fraction

(22) "NonRenewable Energy Consumed (Able to substitute for Renewables)"= INTEG

(

+"Potential Renewable Capa. Increase"-Shift to Renewables,

0)

Units: MWh

(23) "NonRenewable Energy Consumed (Unable to substitute for Renewables)"=

INTEG (

-"Potential Renewable Capa. Increase",

91000)

Units: MWh

(24) Norminal NonRenewable Energy Consumed=

Total NonRenewable Energy Consumed-Offset by TGC With Uncertainty

Units: MWh

(25) Norminal Renewable Energy Consumed=

"Renewable Energy Consumed by Co."+Offset by TGC With Uncertainty

Units: MWh

(26) Offset by TGC With Uncertainty=

(STEP(500,2025)-STEP(500,2031))*(0.9+0.2*RANDOM 0 1())

Units: MWh

(27) "Potential Renewable Capa. Increase"=

IF THEN ELSE("NonRenewable Energy Consumed (Unable to substitute for Renewables)"

>0, DELAY1("Capa. Increase by Utility"*"Effect of Infra Flex.", 1) ,0)

Units: MWh/Year

(28) Power Purchase Agreement=

Energy Expense

Units: thousand yen/Year

(29) Relative Cost=

Cost of Renewable Energy-Cost of Nonrenewable Energy

Units: million EUR/MWh

(30) "Renewable Energy Consumed by Co."= INTEG (

Shift to Renewables,

9000)

Units: MWh

(31) SAVEPER =

TIME STEP

Units: Year [0,?]

The frequency with which output is stored.

(32) Shift to Renewables=

IF THEN ELSE("NonRenewable Energy Consumed (Able to substitute for Renewables)"

>(Effect of Relative Cost*Gap Fraction of Energy Mix*Total Energy Consumed
+"In-house Renewables"), MAX((Effect of Relative Cost*Gap Fraction of Energy Mix
*Total Energy Consumed+"In-house Renewables"), 0), "NonRenewable Energy Consumed (Able to substitute for Renewables)"
)
Units: MWh/Year

(33) TGC Cost=
6.5
Units: thousand yen/MWh
http://www.natural-e.co.jp/pdf/small-b_yakkan.pdf

(34) TIME STEP = 0.25
Units: Year [0,?]
The time step for the simulation.

(35) Total Energy Consumed=
"Renewable Energy Consumed by Co."+Total NonRenewable Energy Consumed
Units: MWh

(36) Total NonRenewable Energy Consumed=
MAX("NonRenewable Energy Consumed (Able to substitute for Renewables)"+"NonRenewable Energy Consumed (Unable to substitute for Renewables)"
,0)
Units: MWh

(37) Utility Benefit= INTEG (
Power Purchase Agreement-"Utility Inv.",
0)
Units: thousand yen/Year

(38) "Utility Fraction of Renewables (Actual)"=
Capacity Renewables of Utility/(Capacity Renewables of Utility+Capacity NonRenewables of Utility
)
Units: fraction

(39) "Utility Inv."=

"Capa. Increase by Utility"*Cost of Renewable Energy

Units: thousand yen/Year

Sensitivity Analysis Input

Base Case

Renewable: 11.86+3.16*(1-(1/(1+exp(-0.8*(Time-2022.5)))))

Non Renewable: 14.02+0.96*(1-(1/(1+exp(-0.8*(Time-2022.5)))))

Sensitivity 1

Renewable: 11.86+3.16*exp(-0.4*(Time-2015))

Non Renewable: 14.02+0.96*exp(-0.4*(Time-2015))

Sensitivity 2

Renewable: 11.86+3.16*(1-exp(-0.4*(2030-Time)))

Non Renewable: 14.02+0.96*(1-exp(-0.4*(2030-Time)))

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