Agent-based Simulation of Impact of Environmental Policies on Greenhouse Gas Emissions

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Dissertation

Agent-based Simulation of Impact of Environmental Policies on Greenhouse Gas Emissions

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September, 2017

Abstract

This PhD research aims to prove the hypotheses that agent-based simulation (ABS) approach can be used for supporting the planning of environmental policies by simulating the impact of these policies on greenhouse gas (GHG) emissions. The simulation systems are developed to simulate the behavior of agents and their GHG emissions under the impact of environmental policy, which are respectively developed for the simulation of GHG total amount control and release standard policies in a rubber city project, a policy of electricity sharing, and an environmental tax policy.

Under the pressure of global warming, GHG emissions reduction became a very hot issue in recent years following by a growing number of environmental policies which target to manage the discharge of GHG emissions. These environmental policies mainly focus on the industrial sector and residential sector in urban area. Regarding to industrial sector, the environmental policy for GHG emissions can be divided into two perspective which are total amount control policy in strategic level and release standard policy in technical level. Thus, this research firstly introduced an ABS system named Rubber City Simulation (RCS) developed for visualizing the developing process of a rubber city followed the “rubber city” project. The impact of environmental policies in this project including total GHG amount control and release standard is simulated by designing agent’s individual behavior related with GHG emissions. The result was used for predicting the potential GHG emissions discharge resulted from developing process of the rubber city.

As to residential sector, the environmental policy focus on the residential consumption of GHG related energy which include electricity and gas. Thus, another planning support system based on agent-based approach named Electricity-Sharing Simulation (ESS) is then introduced in this research, which aims to simulate the effect of an electricity sharing policy on improving the using efficiency of PV generated electricity inside smart communities. To reflect the difference of life routine, an energy consumption model is used for the simulation of household electricity consumption curve which is set as agent’s parameter in the ESS. Electricity sharing is then created as an interaction between households, the simulation result is used for evaluating the effectiveness of the policy.

Furthermore, besides electricity, another major perspective of GHG related energy in residential sector is gas. Therefore, this research also focus on the simulation of policy impact on household gas consumption. We finally introduced an ABS system named Environmental Tax Simulation (ETS) which combined individual consumption behavior with interactive behavior to simulate the impact of an environmental tax policy on residential gas consumption. Through the simulation under different scenarios, the ETS is able to evaluate the effect of the environmental tax policy from different perspectives.

As proved by published research papers consisting in this dissertation, the ABS systems can be used to reflect the impact of environmental policies by designing agents' individual behavior and interactions. Further, the simulation result can present the change in value of GHG emissions corresponding to the change of agent's behavior and interactions. Thus, the ABS systems we introduced in this PhD research are able to forecast or evaluate the effects of environmental policies on GHG emissions, and thereby can be utilized to planning support of urban environmental policy.

Keywords: Agent Behavior Design, Total GHG Amount Control, GHG Release Standard, Environmental Tax Policy, Residential Gas Consumption, Electricity Sharing Policy, Efficiency of PV Generated Electricity Use

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What's more, I sincerely thank all of my friends in Kanazawa University especially the students of urban planning laboratory and students of Japan-China-Korea Environment & Eco-Technical Special course. We had a lot of communications in such a fantastic international environment which significantly opened my mind. I treat our friendship as most precious treasure in my life.

Last, but not least, I am particularly grateful to my parents who made my strong backing. My father passed away when I was studying in the PhD course, I believe that you are watching me all the time in heaven. May your faith be with me forever. The largest pride of my life is, and will always be being your son.

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Chapter 1 Introduction

1.1 Research Background and Research Purpose

Nowadays, urban areas keep suffering the threat of energy crisis coupled with the climate change. Ironically, although the proven reserves of fossil fuels increased over past two decades, it is still unable to keep pace with the increasing energy demands which are expected to increase by 60 to 85 percent by 2030(Peter Droege, 2011). The increasing energy demands result in the growing greenhouse gas (GHG) emissions release, which is the most significant driver of observed climate change since the mid-20th century especially in urban area (Frolkis, et al, 2002). 76 percent of the global consumption of coal occurs in cities, even though they cover less than 1 percent of the earth's surface (Sullivan, 2010). Therefore, the reduction of GHG emissions from urban systems is crucial to global GHG emissions reduction and low-carbon development (Zhang, et al, 2014).

There is no doubt that the development and normal operation of urban areas necessarily go with the GHG emissions release under the existing technical conditions, because it is closely related to individual's production and living activities. Thus, the major issue should be balance the GHG emissions with the requirement of developing and living by policy, which makes environmental policy for GHG emissions a very hot topic. In recent years, a growing number of new environmental policies which target to reduce energy consumption and GHG emissions have been proposed. These policy here refers broadly to government actions in GHG emissions management and mainly focus on industrial sector and residential sector in urban area. For industrial sector, there are two major policy perspective: total amount control in the strategic level and release standard in technical level. While, the policy for residential sector works on residential electricity and gas consumption. The environmental policy usually aim to affect people's individual and interactive behavior related with GHG emissions. Thus, the simulation of impact of environmental policies on people's behavior is helpful for planners to predict or evaluate the effect of the policies for reducing GHG. Among the simulation approaches, Agent-based Simulation has been widely considered to be a powerful approach to simulate the agent's behavior and interactions during urban developing and operating process.

Therefore, This PhD research targets to supply environmental policy makers with planning support systems which can simulate the impact of environmental policy on GHG emissions. We designed the agent's behavior and interactions under the impact of public environmental policies and simulate the effect of these policies on GHG emissions based on agent-based approach. In this PhD research, 3 agent-based simulation systems are proposed to support the planning of environmental policy. Virtual cities and communities which can reflect the urban operation and developing process were implied as simulating environment. Meanwhile, we designed agent's behavior and the interactions based on environmental policies successively including total amount control and release standard policy in "rubber city project" of Thailand, a policy for electricity sharing in Japanese smart community and an "environment tax policy" in Japan. By simulating the impact of these policies on households' behavior, the results should be able to show change in value and general trend of GHG emissions or energy consumption during urban operation or developing process. Moreover, by adjusting the parameters and observe the corresponding simulation result, planners would be able to more easily understand the impact of these policies on GHG emissions.

1.2 Literature Review

1.2.1 Policy Analysis for Planning Support

As showed by existing researches, there are kinds of environmental policies supporting government to manage on different urban environmental issues. These policies cover a very wide range of aspects and take effect in several way such as total amount control, tax for discharge, improving development of new technology and so on (Almer et al, 2017). Regarding the research of analyzing the effect of environmental policies, the related literatures are vast, while can be generally classified in to three perspectives according to the methods: statistical analysis, survey, and simulation.

The statistical analysis has been proved as an effective approach in describing the impact of the environmental policies. Most researches based on statistical analysis are conducted by applying the data to some mathematic models. For example, Ghosh et.al compared the efficiency, distributional and emission leakage effects of border tax adjustments as port of unilateral climate policies by CGE model with statistic data (Ghosh et.al, 2012). Moreover, Rocchi et.al analyzed the potential economic impacts of the reform of European energy tax directive using statistic data of 27 counties in Europe (Rocchi et.al, 2014). Through statistical analysis, researches could be done in a large scale. However, the limitations of researches based on statistical analysis includes the hidden of individuals' heterogeneous and limitations on variable control, which may lead to the deviation while explaining the result. This approach is hereby weak to uncover the underlying process that affect individuals' behavior and also hardly to forecast the potential effect for new policies.

Researches on effect of environmental policy based on survey usually explore the influence of policy on individual's behavior. Schaffrin et al conducted an investigation of energy practices of different social groups to verify the effectiveness of policies targeting household energy conservation based on the survey data of Denmark, Austria and UK (Schaffrin et al, 2015). Mats Bladh and Helena Krantz studied the energy saving behaviors in residential sectors using metered data of a large sample and interview data with a small sample (Mats Bladh and Helena Krantz, 2008). Such kind of method focus on link of policy-behavior-result which make it possible to analyze the effect of policies on individual's behavior and further forecast the effect on pollution and emissions discharge or energy saving. Researchers analyzed the relationships between policies, the location and intensity of urban activities and urban environmental problems (Alberti,1999; Chin, 2002; Ewing, 1994, 1997; Neuman, 2005). However, these researches were mainly qualitative and quantitative analysis that cannot reflect individuals' decisions flexible.

In recent years, researches on simulation of environmental policy models have sprung up, there have been researchers using the various models to forecast or evaluate the impact of environmental policies. For example, Galinato et.al simulated an integrated tax-subsidy policy for carbon emission reduction in the electric power and motor fuel industries (Galinato et.al, 2010). However, with an overview of the model for environmental policies, little attention has been paid to model the impacts on households' behavior (Motawa I and Oladokun M, 2014). Moreover, considering the complexities of the urban system, equilibrium conditions are not easily reached. And relationship identified using these models does not readily revealed the dynamic process leading to the relationship which weaken the effectiveness of these models for planning support.

1.2.2 Agent-Based Simulation of Policy Impact

As reported previously (Jager, 2007), agent-based approach is expected to contribute to the exploration of the effectiveness of public policy measures in complex environments through the simulation of heterogeneous behavior and interactions. A number of studies have used ABS to assess future socio-ecological consequences resulting from public policies (Lee, 2010), meanwhile some other studies have focused on the use of multi-agent simulation for policy development (Berger, 2006). For example, Chen Ping et al simulated the decision making process of household choosing a shop considering the distance, the price, the shop facility conditions (Chen Ping et al, 2006). Yan Ma et al simulated a residential promoting policy effects on downtown revitalization using an agent-based household residential relocation model (Yan Ma et al, 2013). Jordan R et al created an agent-based model of residential mobility and simulated the impacts of a specific urban regeneration intervention (Jordan R et al, 2014).

As a bottom up approach, ABS has been proved to be a useful simulation method to mimic the activity of whom have ability to do their own decisions, this method has been widely utilized to reflect the flexible actions of human beings (Fontaine and Rounsevell, 2009;Brown et al., 2008; Torrens, 2007). Meanwhile, it has the function of creating interactions between agents, which made it possible to model the decision making process with many variables especially for the individuals in a complex environment. Thus, some researchers use it researching on public policy of pollutants control and energy management. While regarding to the possible effectiveness of such policy, we referenced some researches of policy effectiveness evaluation. Ma tried to use agent-based approach supporting government decision-making of total amount control for household water consumption (Ma et al, 2010). There are also researches that concentrate on simulating the dynamic interactions between household behavior, policy making and environmental influences (Vlek, 2000; Jager and Janssen, 2003). These simulations significantly contribute to the study of behavior-environment interactions, and provided a valuable tool for exploring the effectiveness of environmental policy in complex environments (Jager and Mosler, 2007).

1.2.3 Conclusion for Literature Review

The literature review of this research includes different methods for supporting policy analysis. The result indicates that while traditional approaches have been extensively and successfully used in the planning of environmental policies, they have limits in studying the underlying process that reflect the heterogeneous behavior of individuals in situations where decision-making are made under conditions of deep uncertainty. Nevertheless, the heterogeneous behavior under the influence of environmental policy is assignable for simulate the effect on GHG emissions particularly when they are to be employed as planning support system (Torrens 2002).

Comparing with these traditional approaches, agent-based approach is capable to better serve these situations. By accurate design of agent's behavior, it can be very suitable for simulation on effect of policies and individual activities in virtual environment. Because ABS can evaluate the impacts of policy at the level of decision making units such as plantations, factories and households rather than focusing on the aggregate information of groups of individuals to predict policy impacts, while at the same time estimates of aggregate outcomes can still be derived by summing up individual predictions. Flexibility in designing new action rules and environment constraints in a simulation allows planners to test new policy concepts.

Despite the well-documented ABS for modeling, surprisingly there are few research has addressed effects of urban environmental policy on GHG emissions and energy management. For filling up this gap in the existing researches, this PhD research seeks to explore ABS to simulate the possible effect of different environmental policies on GHG emissions with different impact on agent behavior.

1.3 Research Method and Thesis Organization

This PhD research postulates that it is possible to formulate simulation models for supporting the planning of environmental policy based on agent-based simulation approach. For confirming the hypothesis above, three ABS systems for simulating the impact of environmental policies on GHG emissions were constructed. The whole process of model formulating in this research includes extracting the policies, designing agents' behavior and interaction, selecting parameters, and simulation experiment. This research focused on the GHG amount control and release standard policy in a rubber city project, a policy of electricity sharing for energy management in smart community and an environmental tax policy, meanwhile the most important point is how to reflect the influence of these policies on agent's individual and interactive behaviors related with GHG emissions discharge or energy consumption. This research explored a way to reflect the policy impact in the simulation which is setting new decision making process in agent's individual behavior and create new brand of interactions between agents according to the descriptions of target policy. The output of this research are simulation systems that can show the value of GHG emissions discharge and energy consumptions under the impact of environmental policies during urban development or operation.

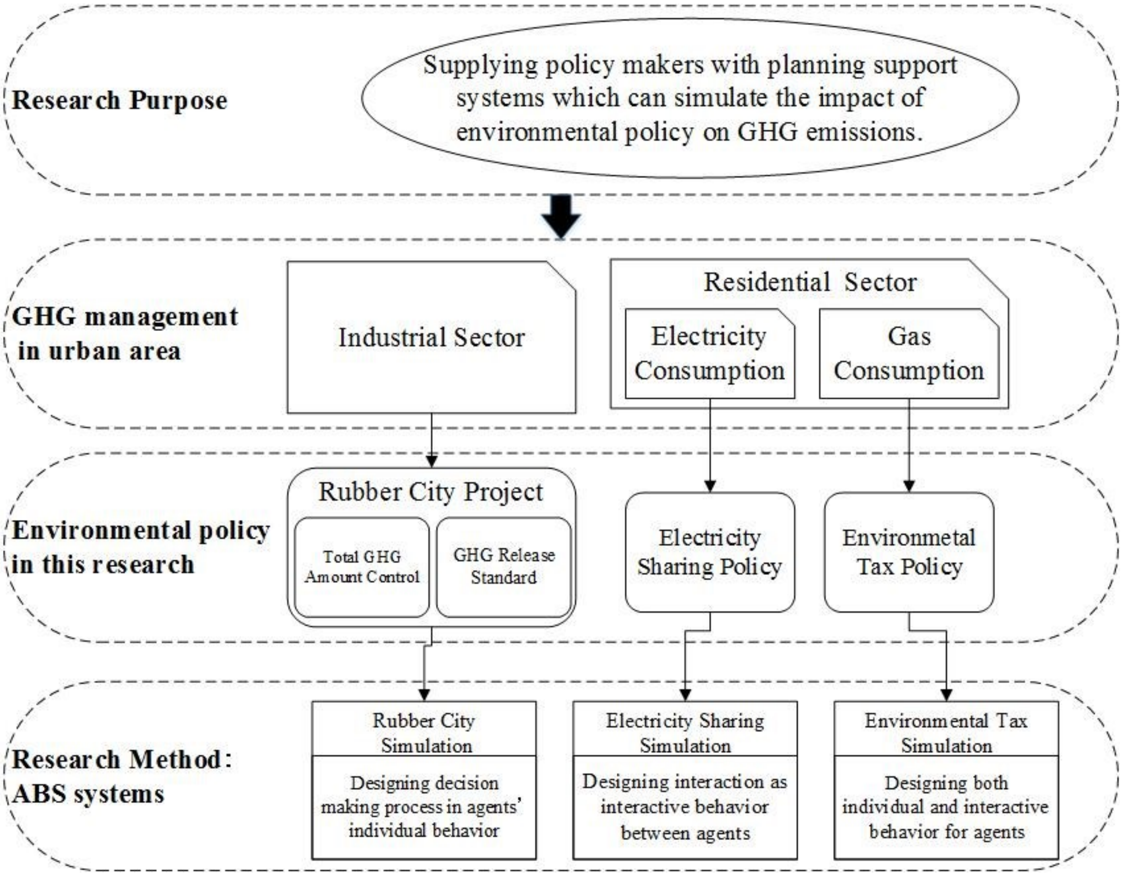


*Figure 1-1.*Structure of Research

The Dissertation is organized by five Chapters. After the introduction of research background, research purpose, literature review and research method in Chapter 1, we start from an agent-based simulation for environmental policies including GHG total amount control and release standard in rubber city project in Chapter 2. An ABS system named Rubber City Simulation (RCS) was developed for visualizing the developing process of a rubber city. The behavior of agents in the system followed decision making processes which designed based on real situation of government and factories in rubber city. Therefore the impact of environmental policy in this model is represented by individual behaviors of factory and government agent. The simulation results consists of change in value of GHG emissions released from different agents and total emissions during the developing process of the rubber city.

The systems above simulate the impact of environmental policy mainly by designing decision making process for agents' individual behaviors. Subsequently in chapter 3, an ABS system named Electricity Sharing Simulation (ESS) is introduced. The system combines 2 parts that make it not only be able to simulate the energy consumption of individual household but also be able to simulate the effect of an electricity-sharing policy on improving the using efficiency of PV generated electricity in smart community. Comparing with the system introduced in previous chapter, we simulate the electricity policy by creating new interactions based on the description of the rule suggested by electricity-sharing policy. The results can be used for the evaluation of the effectiveness of electricity sharing policy for smart communities.

Following Chapter 3, Chapter 4 is about agent-based simulation of the effects of an environmental tax policy in Japan. Another planning support system named Environmental Tax Simulation (ETS) is introduced in this chapter. The influence of environmental tax is simulated by not only inserting it as an parameter into the gas consumption behavior of household agents, but also considered the interactive behaviors for saving gas consumption between household agents. In this way, the promotion of residential environmental awareness and technology improve by the environmental tax policy are also considered in the system by simulation under different scenarios. The comparison of simulation results and statistic data provided the verification for the model. Meanwhile, results of residential gas consumption and CO_2 emissions were addressed under different scenarios of the environmental tax policy. Finally, we will make a conclusion for this PhD research in Chapter 5.

Chapter 2 Agent-based Simulation of Total Amount Control and Release Standard Policy for GHG in "Rubber City" Project

2.1 Introduction

Thailand has been the world's largest natural rubber producer since 2003, and has a share of about 35% of the latex produced worldwide. In 2011, Thailand produced about 3.4 million tons of fresh latex with an average yield of 1.6 ton fresh latex per hectare. The fresh latex is tapped and collected as a liquid, and then processed to primary rubber products. The primary rubber products are then processed into various final rubber products. Important primary rubber products include concentrated latex, block rubber, and ribbed smoked sheet rubber.

The economic lifetime of rubber plantations in Thailand is around 20–25 years. During the first seven years the trees grow without possibilities to tap latex. This period is followed by 13–18 productive years. Fresh latex is extracted by tapping from the rubber trees. The fresh latex is collected as a liquid. The fresh latex can then be processed to primary rubber products, which are subsequently processed to different final rubber products. The most important primary (intermediate) rubber products include concentrated latex (raw material for dipped products such as medical gloves and condoms, represented by CL further below), block rubber (raw material for high viscosity products such as soles and belts, represented by STR further below), and rubber ribbed smoked sheet (raw material for vehicle tires and industrial rubber parts, represented by RSS further below).

Concentrated latex is the primary rubber product used as the raw material for dipped rubber products such as condoms, gloves, balloons, and infant pacifiers. Most of concentrated latex (about 70%) produced in Thailand is exported, mainly to European countries, China, India and Malaysia. In 2011, Thailand exported about 880,000 tons of concentrated latex, with a value of 77,000 million baht.

The ability to measure and control the various physical aspects and characteristics of the baled Standard Rubber has brought about a major change in the rubber industry. There is a drastically increasing demand for these rubber bales as they provide ease in quality control at both reception and processing of the end-user for raw materials. In the case of Thailand, STR comprises of 4 main groups-- STR10, STR20, STRxL and STR CV- depending on the specific control variables.

Ribbed Smoked Sheet Rubber is commonly known as RSS. It is made directly from fresh latex which is treated and then made to coagulate. The coagulated latex sheets are then air dried or smoked in ovens. The smoked sheets are visually graded on the basis of certain parameters and then packed in bales. The size and weight of the bales differs according to country. In Thailand the standard packing for RSS is large bales of 111.11 kg.

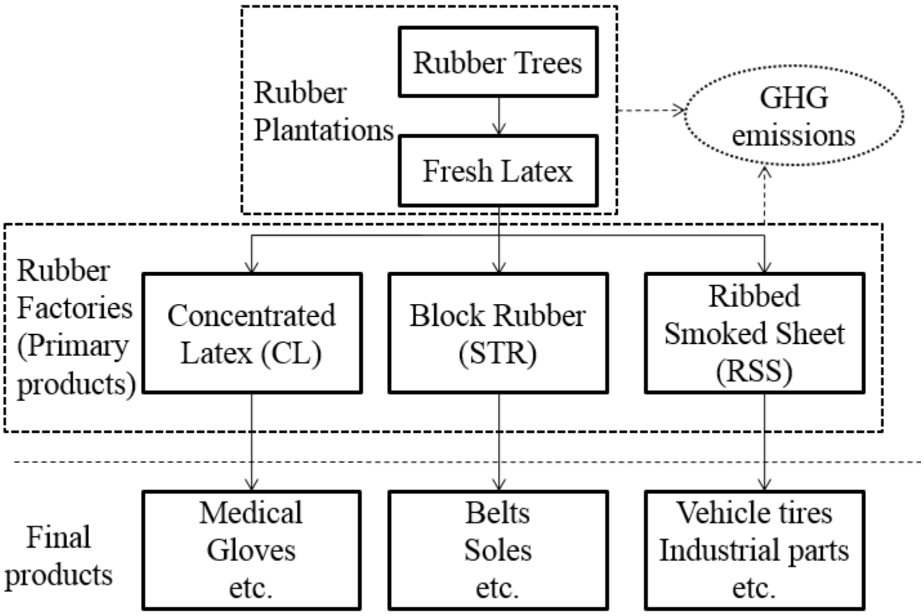


*Figure 2-1.*Industrial Structure Sketch of Rubber Industry in Thailand

Global warming has been gaining attention from the industrial sector during the last decade for Thai government especially after suffered the rainstorm disaster in 2010. The rubber industry is identified as high-emission industry because both agricultural activities in plantations and producing activities in factories release considerable quantities of greenhouse gas (GHG) emissions into the air.

Since natural rubber products are being exported to the international market, it has been challenging for Thai rubber entrepreneurs to seek for appropriate environmental measures to produce environmentally friendly rubber products. Traditionally, environmental management in rubber mills focused on pollution reduction, especially through wastewater treatment and air pollution control. Thailand has signed the Kyoto protocol in 1998, and is currently implementing a strategic climate plan for the period 2008–

2012. This plan consists of six important strategies, including building capacity to adapt to climate impact, promoting greenhouse gas mitigation, and creating awareness. According to Thailand's initial national communication, Total GHG emission were 286 Tg CO2-equivalents in the mid-1990s, of which about 75 Tg are from land use change and forestry, about 60 Tg from agriculture, and about 15 Tg from industry.

In 2013, the government of Thailand has agreed to cooperate with Malaysia on a Rubber City project which means building primary rubber industry in the city with good foundation of rubber plantation. Thailand and Malaysia have agreed to create a Rubber City along their border to raise the rubber prices. The two sides agreed to strengthen their cooperation in trade and investment, particularly in the areas that they share strength like Halal food and rubber. Malaysia proposed the establishment of the Rubber City along the Kedah-Thai border for the mutual benefits. Under the proposed project, the city will be created in the border area linking Dan Prakob in Songkhla's Nathawi district and Kota Putra in the Malaysian state of Kedah. Thailand is currently a major source of rubber for Malaysia, while the country wants to learn about the latest technology for rubber production from its southern neighbor. The Rubber City project should be mutually beneficial, as Thailand has the greater supply of rubber while Malaysia has several industries making products from it. The project will also help increase the price of rubber and create sustainable incomes for Thai farmers.

Although the main purpose of rubber city project is to develop local rubber industry, the government also considered the environmental impact of the project. Some environmental policies are mentioned in the statement for the rubber city, including several issues such as waste water, soil pollution and so on. Although the policies related with GHG emissions are quite rough, they can be summarized as strategic policy and technical policy. In strategic level, the policy is set for total amount control, it can be described as: the whole rubber industry including plantations and factories should control the GHG emissions and keep the total emissions under 10000 ton CO_2-eq per year. If the value beyond 10000 ton, the approval process of creating new factories will become austerity that only if there are plantations closed, it is possible to create new factories.

Meanwhile, in the technical level, government set standards of the GHG emissions discharge with unit production with the purpose of requiring rubber factories improving their GHG reduction technology. The details are listed in table 2-1. The factories whose annual output ranked within top 20% of whole industry should achieve the requirement of level 1; the factories whose annual output ranked within top 50% of whole industry should achieve the requirement of level 2; besides, all factories should achieve level 3 which is the minimum standard.

Table 2-1. Standard for rubber factory (kg CO_2-eq/ton)

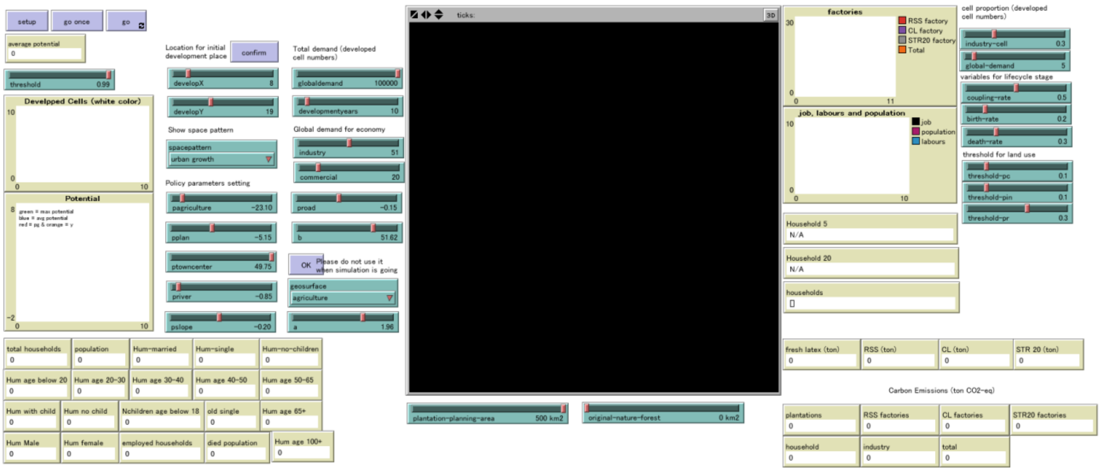
Production	CL	STR	RSS
Level 1	20	150	11
Level 2	23	155	13
Level 3	25	160	15

This chapter aims to predict the GHG emissions of Nathawi district in first 10 years after the “Rubber City” project implemented in local area. A planning support system for simulating the process of urban development and GHG emissions of the rubber city was developed. During system design, we focus on the simulation of the effect of environmental policy in “Rubber City” project by designing the decision making process for agent behavior. The simulation result showed the annual value and changing trend of GHG emissions discharge in rubber city. Based on the result, effectiveness of the environmental policy for total GHG amount control and technology updating are evaluated. Furthermore, some suggestions are given for the planning of environmental policy in “Rubber City” project in the aspect of GHG emissions reduction. Meanwhile, the future developing directions of the simulation system are summarized based on the performance of the RCS in the simulation

2.2 System Design for Rubber City Simulation

2.2.1 *System Interface and Framework*

The system interface consists of display, monitors, plots, buttons and sliders. And it contains 3 functional part including controlling part for setting the parameter for the simulation, urban status monitoring part for showing the situation of urban development and GHG emissions monitoring part for showing the simulating result of GHG emissions.



average potential 0

threshold 0.99

developX 8

developY 19

globaldemand 100000

developmentyears 10

spacepattern: urban growth

industry 51

commercial 20

pagriculture -23.10

proad -0.15

pplan -5.15

b 51.62

ptowncenter 49.75

priver -0.85

geosurface: agriculture

pslope -0.20

a 1.96

total households 0

population 0

Hum-married 0

Hum-single 0

Hum-no-children 0

Hum age below 20 0

Hum age 20-30 0

Hum age 30-40 0

Hum age 40-50 0

Hum age 50-65 0

Hum with child 0

Hum no child 0

Nchildren age below 18 0

old single 0

Hum age 65+ 0

Hum Male 0

Hum female 0

employed households 0

died population 0

Hum age 100+ 0

plantation-planning-area 500 km2

original-nature-forest 0 km2

industry-cell 0.3

global-demand 5

coupling-rate 0.5

birth-rate 0.2

death-rate 0.3

threshold-pc 0.1

threshold-pin 0.1

threshold-pr 0.3

Household 5 N/A

Household 20 N/A

households

fresh latex (ton) 0

RSS (ton) 0

CL (ton) 0

STR 20 (ton) 0

plantations 0

RSS factories 0

CL factories 0

STR20 factories 0

household 0

industry 0

total 0

Figure 2-2. System interface

While the “setup” button is clicked, the system will read the programming code and set the initial conditions for the simulation. Clicking “go” button means starting the simulation, the function of “go once” button is totally same with “go” button, but the simulation will just last 1 tick while it is clicked. Sliders are used to set the initial parameters for the simulation. Both monitors and plots are for making the simulating result visible. Monitors show numerical results and the results are more intuitive in the plots. The set of sliders, monitors and plots in left side constitute the urban status monitoring and controlling part of the system. And the right side is GHG emissions monitoring part. The simulating result which is used for predicting in this research are obtained from here.

The system framework can be divide into 2 parts: preparation and simulation. During preparation, the system load the virtual city as simulating environment and set the initial plantations in the city. Those plantations represent existing plantations of rubber city. Then policy constraints are input as initial parameters in order to simulate the policy impact of developing rubber city.

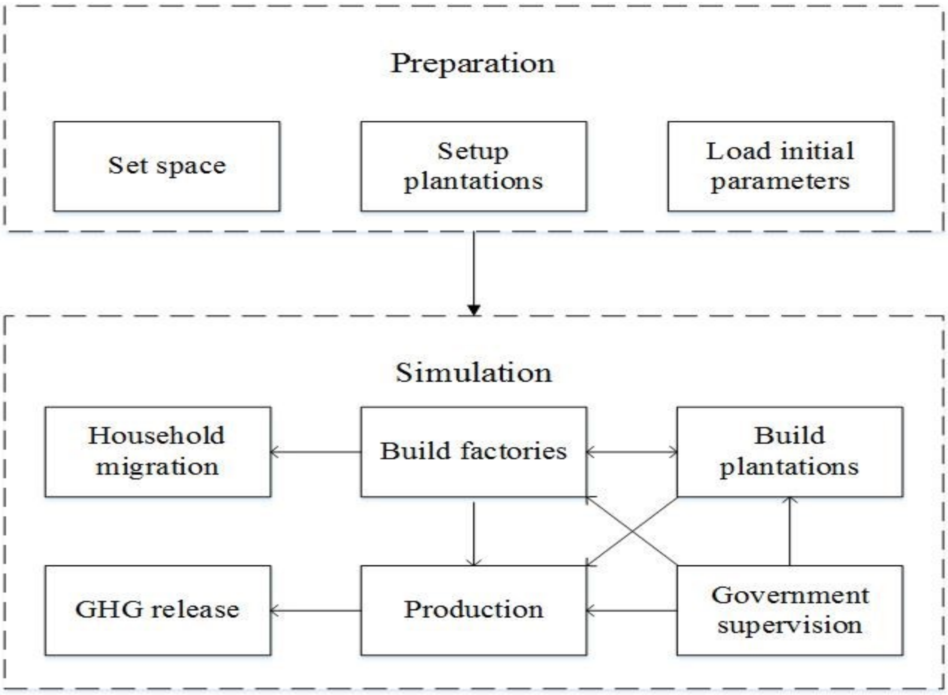
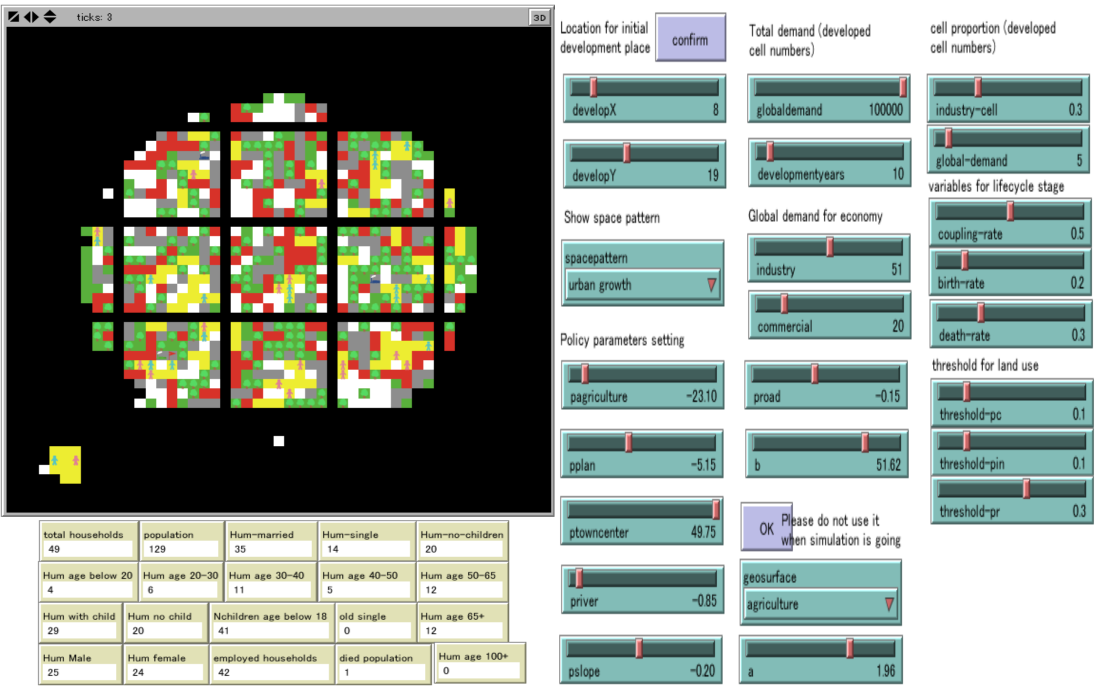


Figure 2-3 System Framework of RCS

Following the preparation is simulation. At the beginning of every tick which is the time unit of the simulation, the system firstly check whether it is possible to create new factories, if the results is “yes”, new factories will be created. Then the system will judge whether the total amount of FL is enough for industrial production, in other word, is it necessary to create new plantations. If it is necessary, new plantations will be built to supply more FL. Then, because of the job chances in new factories and plantations households will be attracted and decide whether migrate to local area and later start their life cycles. The processes above form the development of rubber city, the system base calculation of GHG on the productions of agents. The amount of GHG Basically calculated with the output of rubber products produced by agents.

2.2.2 *Environment, Agent and Interactions*

In this research, a virtual city which is a typical job-oriented one is defined based on the conditions of Nathawi district in the system. In this virtual city, it is assumed that the driving power of urban development is job, moreover, the job chances are provided while factories are being created and the job in plantations are occupied with native of Nathawi. The land use development of the virtual city is based on Cellular Automata theory. For initial stage, this city has a downtown area, several road and a river, with simulation progress processing, each parcel (represent urban area) will calculate the develop potential by the correlation of river, road, slope, agriculture, plan, distance to downtown, and neighborhood effect, if the develop potential is bigger than threshold, this parcel will decide to be developed. If one parcel decides to be developed, then it will calculate the potentials to be developed to 4 kinds of land-use type, which are industrial land-use, commercial land-use, agricultural land-use and residential land-use. If the biggest one of the potential is higher than the threshold, this parcel will decided to be developed as corresponding land-use type. Among the 4 land-use types, only agricultural land-use relate to the simulation of this research, so one patch with agricultural land-use takes area of 2.38 km^2. Based on this, total area of agricultural land in the virtual city is about 560km^2 consist of approximately 235 patches in the system while patches with other land-use type are not defined specific area. The developing conditions of the virtual city can be controlled via changing parameters by sliders and button in the system. While the developing situations also can be observed directly in the display or by the data monitors in the system.



developX 8
developY 19
globaldemand 100000
developmentyears 10
industry-cell 0.3
global-demand 5
spacepattern: urban growth
industry 51
commercial 20
coupling-rate 0.5
birth-rate 0.2
death-rate 0.3
pagriculture -23.10
proad -0.15
threshold-pc 0.1
pplan -5.15
b 51.62
threshold-pin 0.1
threshold-pr 0.3
ptowncenter 49.75
priver -0.85
geosurface: agriculture
pslope -0.20
a 1.96

total households 49
population 129
Hum-married 35
Hum-single 14
Hum-no-children 20
Hum age below 20 4
Hum age 20-30 6
Hum age 30-40 11
Hum age 40-50 5
Hum age 50-65 12
Hum with child 29
Hum no child 20
Nchildren age below 18 41
old single 0
Hum age 65+ 12
Hum Male 25
Hum female 24
employed households 42
died population 1
Hum age 100+ 0

Figure 2-4. Controlling parameters of urban growth for virtual city

Four kinds of agent were designed in RCS system. They have their own attributes and behaviors in the simulation system. Behaviors which are operating principle of agents decide how agents would change during the simulating process and will be introduced in the following section. Attributes partly set as parameters by users and also come from the simulation. They directly affect the numerical calculation in the simulation and the final result of greenhouse gas emissions. Plantation means long, artificiallyestablished forest, farm or estate, where crops are grown for sale, often in distant markets rather than for local on-site consumption. Plantations are grown on a large scale as the crops grown are for commercial purpose. So the produce of plantations often be machined into the form which is easy to be transported by processing factories. In this research, Plantations refer in particular to rubber plantations. The attributes of plantation agent are listed in table 2-2

Table 2-2 Attributes of Plantation Agent

Attribute	Explanation
Location	The place where plantation locate in (express by coordinate x,y)
Area	Area of plantation
Unit output	Annual yield of fresh latex of unit area in plantation

Factories of rubber city work for making fresh latex into final consumption goods or the intermediate products which are easily transported. According to the "rubber city" project, the factories that produce primary rubber products will be built in Nathawi. Three different types of factory agents are set in the system according to the 3 most important primary products of rubber industry which are ribbed smoked sheet (RSS), concentrated latex (CL) and block rubber (STR 20). 3 types of factories have same categories of attributes while the value of some attributes maybe different based on the characteristics of factories. For example, the annual output of a RSS factory is likely to be different with a CL factories. The attributes of factory agent are listed in table 2-3.

Table 2-3. Attributes of Factory Agent

Attribute	Explanation
Location	The place where factory locate in (express by coordinate x,y)
Type	Products of factory (RSS, CL or STR 20)
Job chance	The number of workers that the factory need
Output	Output of products of the factory

Household agents represent the human population, people correspond not to individual agents in the system, but rather members of households. A household is an agent, which is a coherent unit of simulating process, and can make decisions as a single entity. This single entity is assumed to be composed of a family consisting of one or more people. The household agents in the system consist of 2 part, one part is native of Nathawi district, and the other is households being attracted by job chance of new factories then migrate to Nathawi district.

Table 2-4. Attributes of Household Agent

Attribute	Explanation
Location	The place where household locate in (express by coordinate x,y)
Work place	Where do individuals work (plantation or factory)

Government agent is invisible in the system, it takes charge of the approval of creating new plantation and factories.

Interactions are used to define how all kinds of agents and environment affect each other. The interactions of this research include interactions between agents along with interactions between agents and environment. There are 4 main interactions which may affect results, they are:

- Plantation agents produce fresh latex for factory agents as the raw material.
- Government agent takes charge of the approval of new factories and plantations.
- Household agent hunt jobs in plantations and factories.
- Plantations, factories and households locate in and release GHG to virtual city.

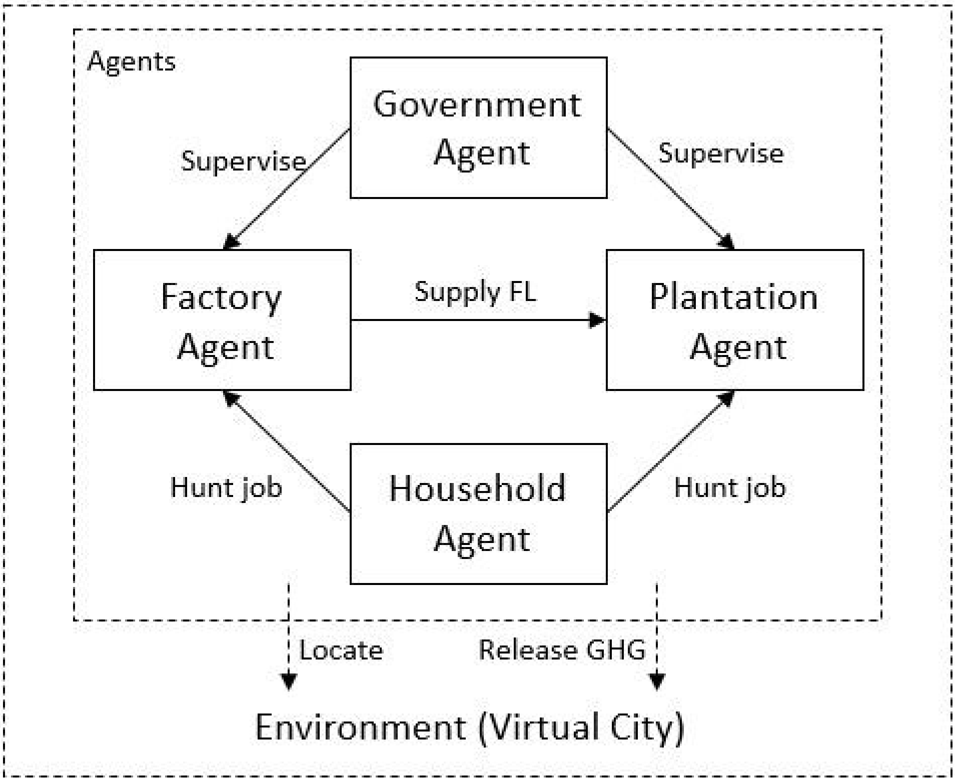


Figure 2-5. Interactions among the agents and between agents and environment

2.2.3 *Estimation of GHG emissions*

GHG emissions are released from agents as GHG source in the system. A GHG source is any process or activity that releases GHGs into the atmosphere. This research is focus on rubber city, the process or activity related to rubber industry will be taken into account. The GHG sources discussed in this study are agricultural production in rubber plantations, and industrial production in rubber factories. Therefore, the total GHG emissions are divided into 2 parts: GHG emissions from rubber plantations, and GHG emissions from rubber factories. GHG emissions of the 2 parts are summed up to get the total GHG emissions as the equation shows:

$$GHG_{total} = GHG_p + GHG_f \qquad \text{eq. 2-1}$$

The GHG emissions of each part are calculated by output of productions multiply the emissions factors of corresponding production. The emission factors are estimated based on the number of GHG used in activates during producing process of productions. All of results are converted to CO_2 equivalent value. Equation 2 is the calculating method of emission factors:

$$E_x = \sum_{i,j,k} A_{x,i,j} \times G_{j,k} \times GWP_k \qquad \text{eq. 2-2}$$

Where Ex is GHG emission factor of product x (kg CO_2-eq/ton). $A_{x,i,j}$ means the consumption of material j in the activity i in order to produce 1 ton product x (kg/ton). $G_{j,k}$ means the emission of GHG k while using 1kg material j (kg/kg). GWP_k is the global warming potential of GHG k which is able to convert GHG into CO_2-eq (kg CO_2-eq/kg)

GHG emissions from rubber plantations (I) due to land conversion, (II) from the production of raw materials used in rubber plantations, and (III) from the production of fresh latex in plantations. Emissions from land conversion are for the case that tropical forest is converted to rubber plantations. As to the Nathawi district, there are plenty of rubber plantations so that new plantations are not likely to be built during the simulation. The production of raw materials used in rubber plantations are not take place in Nathawi district, which means this part of emissions don't released to local area. So, the system only calculate the GHG emissions from the production of fresh latex in plantations during the simulation.

The activities happened in rubber plantations which release GHG emissions include: N_2O direct emission from N-fertilizer use, N_2O indirect emission after N leaching and runoff, N_2O indirect emission after emission of fertilizer N as NO_x and NH_3, Diesel use in tractor for tillage and Diesel use in latex transportation by pick-up car. Considering the GHG emission from all activities above, we can get the result that the GHG emission factor of fresh latex is 85 kg CO_2-eq/ton fresh latex (table 2-5).

Table 2-5. GHG emissions from fresh latex production in rubber plantations (kg/ton)

Activities	Emission (kg/ton fresh latex)			
	CO_2	CH_4	N_2O	CO_2-eq
N2O direct emission from N-fertilizer use	0	0	0.19	59
N2O indirect emission after N leaching and runoff	0	0	0.04	13
N2O indirect emission after emission of fertilizer N as NOx and NH3	0	0	0.02	6
Diesel use in tractor for tillage	0.4	<0.001	<0.001	0.4

Activities	Emission (kg/ton fresh latex)			
	CO_2	CH_4	N_2O	CO_2-eq
Diesel use in latex transportation by pick-up car	7	<0.001	<0.001	7
Total	7.4	<0.001	0.25	85

The GHG emission released from plantations is calculated by output of FL multiply emission factors of FL as equation 3:

$$GHG_p = m_{fl} \times E_{fl} \quad \text{eq. 2-3}$$

Where GHG_p denotes the total GHG emission from plantations (kg CO_2-eq). m_{fl} is total output of fresh latex (ton). E_{fl} is the emission factor of fresh latex (kg CO_2-eq/ton). Usually after 20 year from being planted, the rubber tree start producing fresh latex, thus the production output of plantations can be predicted, in this research, we referenced the prediction value in the 2012 report of Bangkok rubber manufacturers.

GHG emissions from rubber factories are presented in table 5. Emissions are from the industrial production of the three primary rubber products: CL, STR and RSS. For all these 3 kind of products, diesel is necessary for production (Warit Jawjit, Carolien Kroeze, et al. 2010). LPG giving rise to lower GHG emissions than diesel is used in the drying process of STR production. It has been introduced in STR production in Thailand a few years ago, in response to rising diesel prices. In the RSS factories, some wood are burned for smoking rubber sheet in order to get RSS. The wood used for drying and smoking the rubber sheet is from trees that are likely replanted in plantation, so emissions from burning wood are not included in total emissions of rubber factories.

We calculate the emissions factors of CL, STR and RSS separately, and multiply output values of corresponding products respectively. Finally, sum GHG emissions of the 3 parts up to get the total value of GHG emissions from factories. Equation 2-4 shows the calculating process.

$$GHG_f = m_{cl} \times E_{cl} + m_{str} \times E_{str} + m_{rss} \times E_{rss} \quad \text{eq. 2-4}$$

Where GHG_f denotes the total GHG emission from factories (kg CO_2-eq). m_{cl}, m_{str} and m_{rss} respectively mean total output of CL, STR and RSS (ton). E_{fl}, E_{str} and E_{rss} represent emission factor of CL, STR and RSS (kg CO_2-eq/ton).

In this research, we assume that the output of different factories follow a random uniform distribution and set the initial average production output of factories and changing range according to "Annual Statistical Report 2012 of Thai Hua Rubber Public Company" which can be presented by following equation:

$$m_{initial} = m_{average} \times (1 + \alpha) \quad \text{eq. 2-5}$$

Where α follow a random uniform distribution, the changing range and average initial output is different according to the different products.

Meanwhile, for individual factories, its yearly output should be fluctuant. Thus, for describing the yearly change, it is assumed that the growth rate of production outputs follows a random normal distribution. The output every year can be calculated as following equation:

$$m_{t+1} = m_t \times (1 + \beta) \quad \text{eq. 2-6}$$

Where β follows a random normal distribution with mean 0 and SD 0.1.

2.3 Behavior Design for Simulating the Impact of Environmental policy

As the introduction of environmental policies in rubber city project in previous section, at strategic level, the policy is set for total amount control. Thus in the RCS, we designed the behavior of government agent to simulate the effect of the policy.

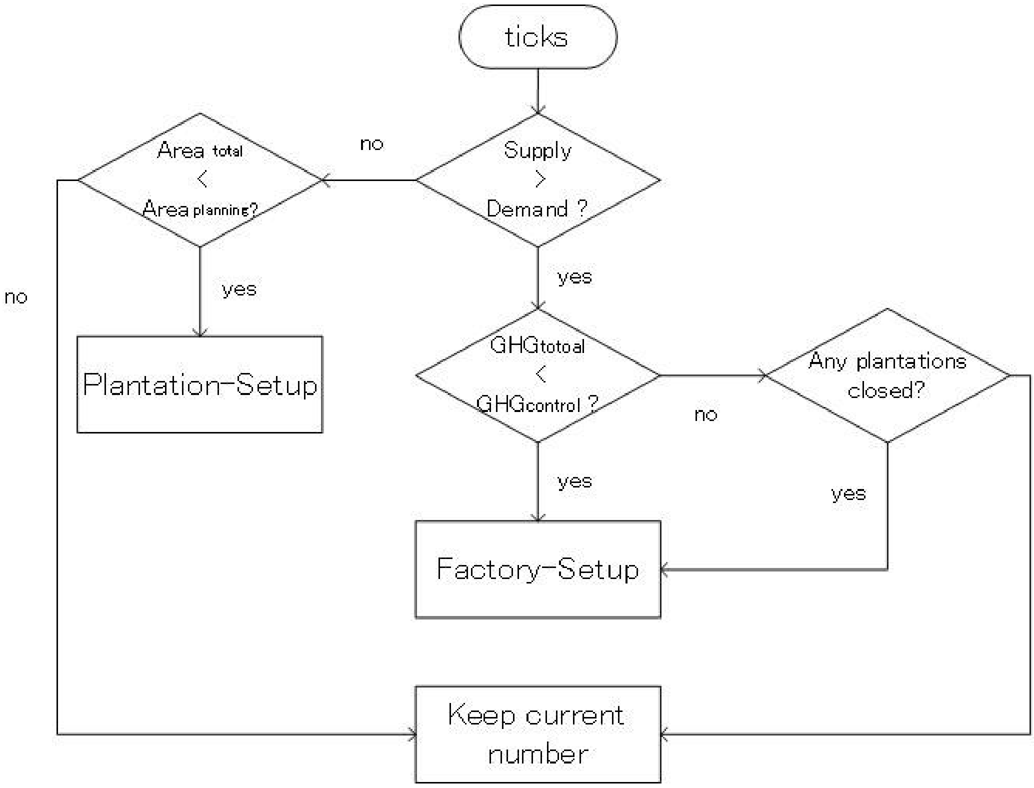


Figure 2-6. Behavior of Government Agent

At every ticks during the simulation, the government firstly summary the total supply and demand of FL. Than it compares these 2 values to check whether the FL produced in plantations is enough for local industrial rubber production. If it is enough, that means it is possible to create new factories, while in opposite situation, new plantations may be created. As the description of the policy, in the case that FL is enough, the government agent will summary the total GHG emissions and compare with the control value, if the total GHG emissions beyond control, only if there are plantations closed in this tick, new factories are possible to be created. After the deterministic process above, the type of new factories is decided by potential of each type. The potential is calculated by the number of different types of factories, in another word, the type of factories with least number have the most potential to create new factory. After that, factory agents will be set and located in the virtual city and starting their behavior including production and GHG discharge. As to the approval process of new plantations, because government of Nathawi district made the limitation on proportion of the rubber plantation among total agricultural land, the government agent manly focus on the total are of rubber plantations. If the actual total area is smaller than planning area that means there are still space for creating new plantation agent.

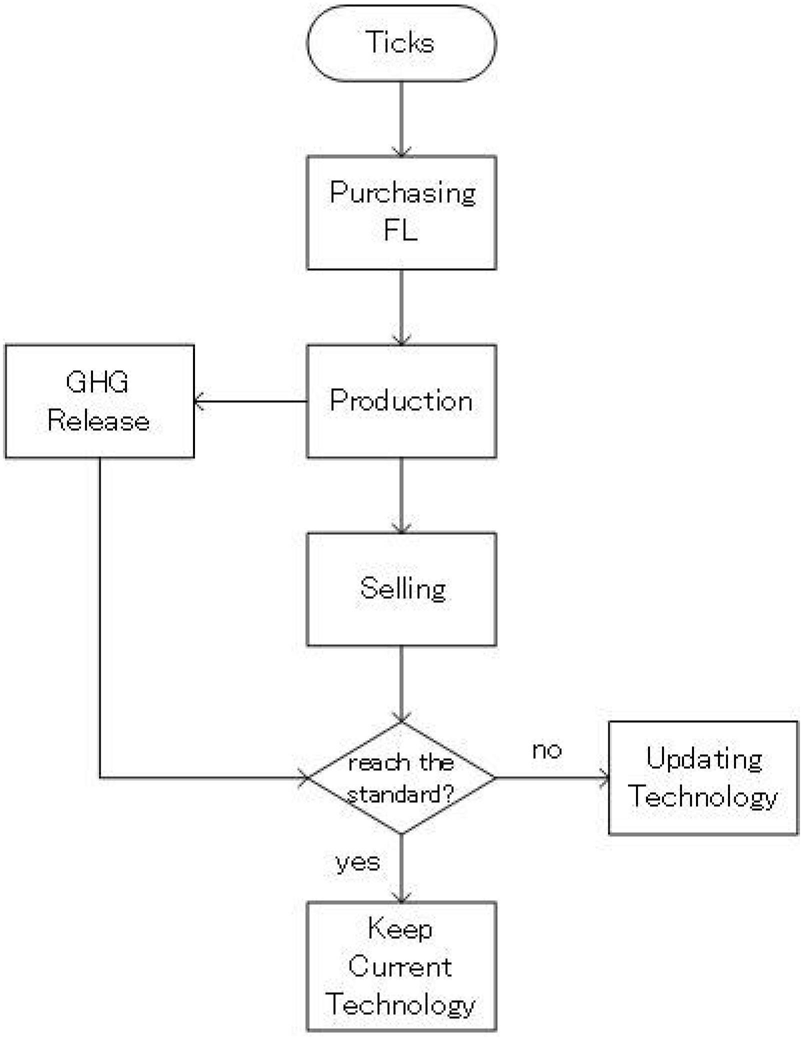


Figure 2-7. Behavior of factory agents

We also designed a decision making process in factory agents' behavior to simulate the effect of environmental policy at technical level in rubber city project. It reflects a judge process of factory agent for determining the necessity of updating its environmental technology. As showed in the figure, at every tick in the simulation, the factory agent purchase FL, then produce productions meanwhile discharge GHG emissions. After selling the products, the factory agent check whether it appropriate to corresponding standard level according to the profit of GHG emissions. The technical updating happens depend on the result.

2.4 Prediction of GHG Emissions for Rubber City Project

2.4.1 *Study Case and Data Preparation*

Nathawi district is located at the south of Songkhla province in the south of Thailand, and has a total area of approximately 747 km^2 and a population of 65721 according to the government website of songkhla province. Nathawi district has been chosen to be pilot city of rubber city by Thai government cause its large area of rubber plantation and undeveloped rubber industries. In 2012, the area of rubber plantations in Nathawi is approximately 491 km^2 which occupied about 87% of its agricultural land use and 66% of its total area as showed in figure 12. 10436 households with more than 30000 people work in local rubber plantations, result in the achievement that 89154ton fresh latex was produced with the average yield of 227 kg/km^2 in 2012.

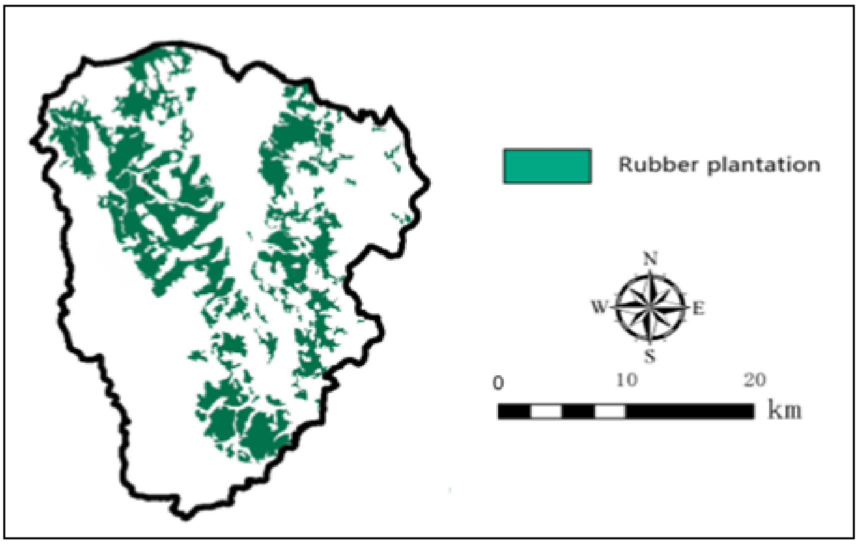


Figure 2-8. Plantation covered are in Nathawi District

In consequence of the undeveloped rubber industry, most of the fresh latex produced in Nathawi is export to other place for further processing, which makes local economy being quite sensitive to price of nature rubber. The dropping rubber price hit local economy very much, hence, Nathawi district suffered with sluggish development and local residence became very anxious. In this case, Thai government planned to stabilize the price of nature rubber and create more job chance by building Nathawi into a rubber city. According to “rubber city project” set by Thailand and Malaysia, rubber processing industries will be built in Nathawi.

Data used for this research including household number, population, agricultural land use area, and total area of rubber plantations are obtained from official website of songkhla agriculture department. The corresponding data on average yield of rubber plantations, output of rubber processing factories and emission factors are searched from existing research and will be used as parameter in the simulating process.

According to the actual situation of Nathawi district, one patch with agricultural land-use type is set taking area of 2.38 km^2, total area of agricultural land in the virtual city is about 560km^2 consist of approximately 235 patches in the system. The existed plantations take 391 km^2 with the actual planting area about 405 km^2 in Nathawi district, so the initial number of plantation is set to 164 with total area of 390.32 km^2.

Agents have different value of products output, they are random but change near the average value which is referenced in existed research. What’s more, the volume of one agent is changing in a reasonable range yearly.

The initial average output of RSS, STR and CL are obtained from “Annual Statistical Report 2012 of Thai Hua Rubber Public Company” as listed in table 2-6.

Table 2-6 Initial parameters of agents

Parameter	value	unit
Initial plantation	164	
Annual output of FL	227.5 （±5%）	ton
Annual output of CL	2500 （±20%）	ton
Annual output of STR	3000 （±16%）	ton
Annual output of RSS	3500 （±14%）	ton

2.4.2 *Simulation Result and Discussion*

The first 10 year’s developing process of Nathawi district as a rubber city with the environmental policy impact is simulated in this research. The simulation was repeated

50 times, and the values used in this research as result are the average values of 50 times' simulation. The results are as shown in table 2-7.

Table 2-7 Result of GHG emissions (ton CO_2-eq)

YEAR	PLANTATION	CL	STR 20	RSS	FACTORY	TOTAL
1	7626.92	74.61	675.86	64.20	814.67	8441.59
2	7608.74	170.28	1255.25	64.70	1490.23	9098.97
3	7620.86	260.51	1094.55	64.20	1419.25	9040.11
4	7637.28	281.63	1306.37	193.88	1781.87	9419.15
5	7634.15	401.28	1273.75	204.21	1879.24	9513.39
6	7607.17	522.62	1099.51	263.82	1885.95	9493.12
7	7593.49	499.13	1421.22	246.72	2167.07	9760.56
8	7637.67	553.55	1440.34	261.44	2255.32	9892.99
9	7601.11	660.69	1402.09	271.52	2334.30	9935.41
10	7643.34	673.86	1466.66	275.30	2415.82	10059.16

Based on the simulation result, we separately discuss the GHG emissions released from plantations, factories and the total emissions.

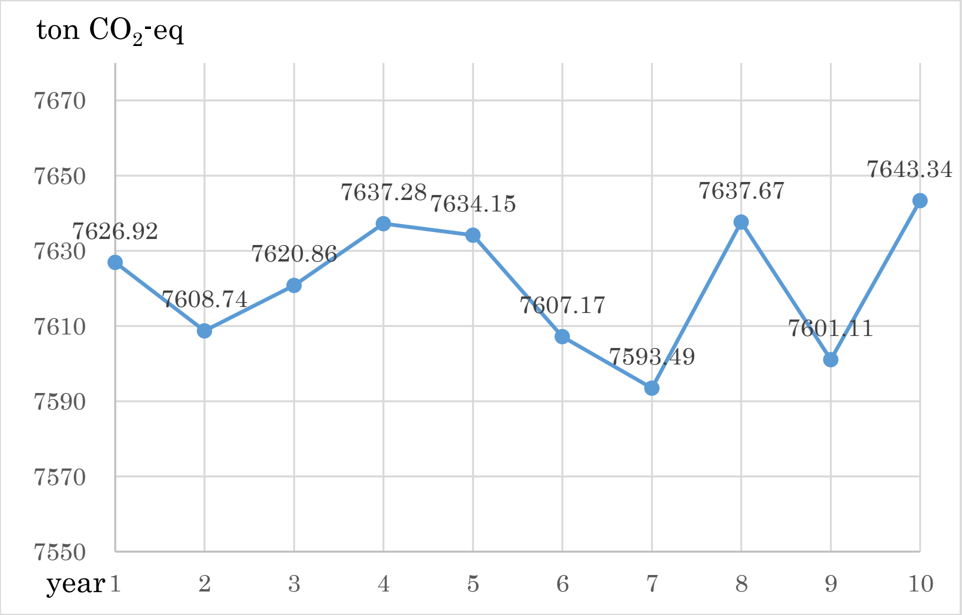


Figure 2-9. GHG emission released from plantations (ton/year)

The GHG emission from plantations don't show obvious yearly growth. It's because Nathawi district have strong foundation in rubber agriculture which is able to supply stable amount of fresh latex for rubber industry. And the rubber factories built within 10 years are not able to cause short supply of raw materials. Moreover, although the limitation on planning area of plantations in the rubber city project is able to control the growth of plantations, there is no standard in the rubber city projects set for the GHG emissions of plantation, which makes plantation the main GHG emission source in the rubber city.

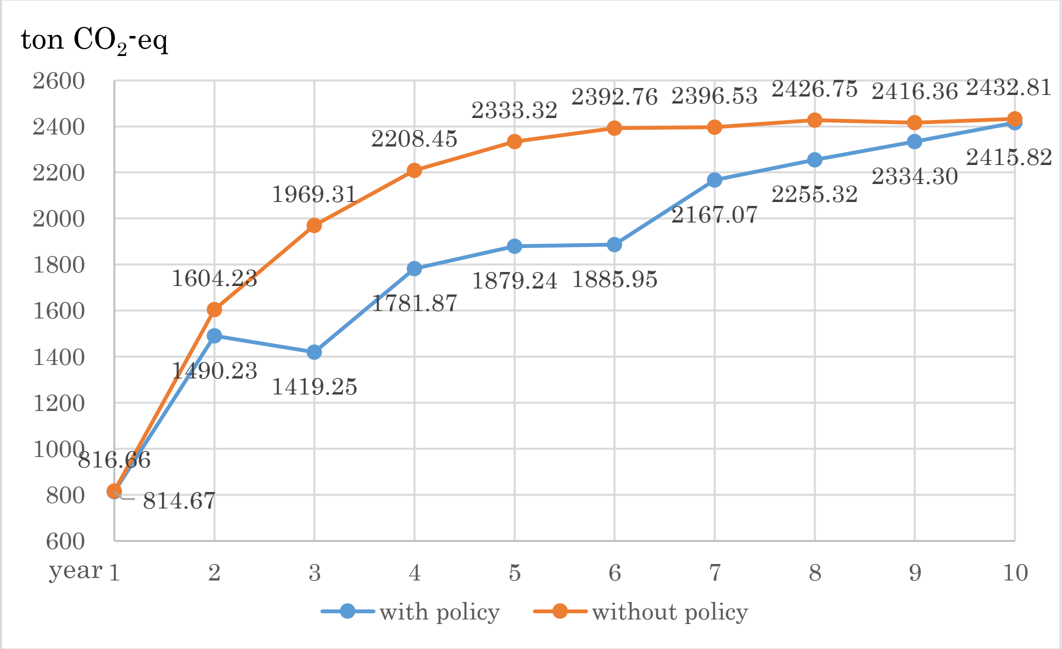


Figure 2-10. GHG emission released from factories (ton/year)

According to "rubber city project", a growing number of rubber factories which produce primary rubber products will be built within 10 years. It causes the steady growth of GHG emission from rubber industry and would finally achieve average 2415.82 ton CO_2-eq in 10th. year according to the simulation result. For a better understanding of the policy in technical level, another 50 times simulation without the decision process of technology updating for factory agent were conducted. The figure above shows the GHG emissions released from factories with policy impact and without policy impact. The average number and output of factories are almost same, while without the policy for technology updating, the GHG emissions rapidly increase until the total GHG of rubber city get to the control value. The total difference of the simulation result with and without policy is 2553.47 ton CO_2-eq which proves that the environmental policy for technical update works quite well. Another evidence is that by the end of simulation, around 25% of factories reached level 1 of GHG standard, around 35% reached level 2.

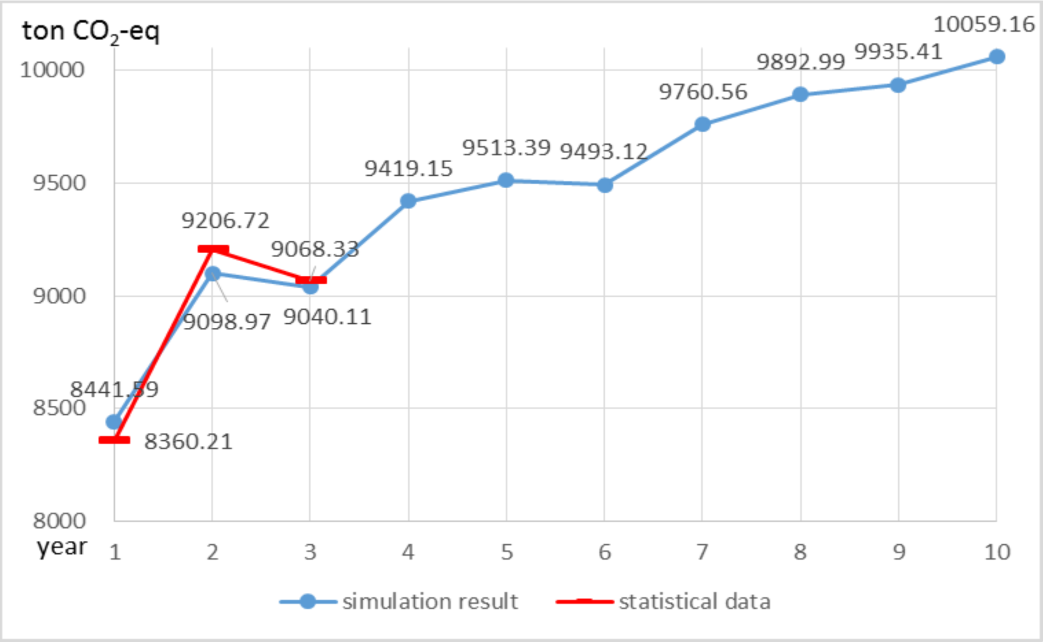


Figure 2-11. Total GHG emission (ton/year)

Although the GHG emission from plantations keeps stable, the GHG of factories grow in the 10 years' time according to the simulation. As a result, Total GHG emission changed from average 8441.59 ton/year to average 10059.16 ton/year during the 10 year of implementing "rubber city" project in Nathawi district according to the simulation system. In the several years of beginning, the growth rate keeps changing. That is mainly caused by the technical updating of factories. While, the value became stable when the total GHG emissions come closed to the control value, which reflected the effect of the environmental policy for total amount control in rubber city project. The average value of 10th year was beyond the control value because the value of output fluctuated in a small range. As a verification, we collect the data of rubber related GHG emission in Nathawi district from 2014 to 2016 according to the report of Bangkok rubber manufacturers. By comparing with the collected data, it can be verified that the simulation totally reflect the change in value of emission well.

2.5 Conclusions for this Chapter

The total GHG emission significantly grows in the 10 years' time during the simulation. It mainly because that growing numbers of factories in the rubber city. The largest GHG source has been plantation agents all the time during the simulation. The amount of GHG emissions released from plantations in Nathawi is quite huge (around

7600 ton CO2-eq/ year), because Nathawi district has a quite good agricultural foundation for industrial rubber production which means a large number of rubber plantations. Another reason is that the production method of FL used by local farmers is behind the times comparing with other rubber producing country. Most of local farmers are using traditional production method to plant rubber tree and produce FL. Thus, during the production, the plantation lack appropriate agricultural management and large number of fertilizer is used which make the emission factor of FL in a quite high level. However, the “rubber city” project doesn’t mention about the environmental policy for reducing the GHG emissions of plantations. So, a conclusion can be drawn that the government should make policy for setting the GHG emission release standard and improving Technical updates for plantations.

Except the plantations, factories take significant amount of GHG emission to Nathawi district in 10 years’ time. It’s worth noting that STR factories take more significant emission growth than CL factories and RSS factories because of its high GHG emission factors. Although recently something named LPG giving rise to lower GHG emissions than diesel is used in the drying process of STR, the GHG emissions factor is still quite high comparing with the other 2 kinds of products. In this case, local government should be more careful with the construction project of STR factory. The policy of setting standard to encourage the technical updates for rubber factories works successfully. That can be proved by the comparison between the simulation result with policy impact and without policy impact. Under the premise of developing local economy, the policy totally reduced 2553.47 ton CO_2-eq GHG emissions.

The policy of total amount control worked to keep the total GHG emissions under the control value. An issues can be observed from the simulation is that the unbalance of GHG emissions for plantation and factories. The efficient of plantation for creating output is low while the GHG emissions discharge is quite huge comparing with factory. Therefore, together with policy for total amount control, government should consider to establish more policy for encouraging the industrial transformation from rubber plantation to rubber industry.

At the current state of the development of system, the results are promising, but still needs further revision. During the simulating process, the simulation system worked smoothly, and apparent error did not occur. Even though the results remain inconclusive, the current simulation system is a good foundation for further developing. However, because of time and data limitation, the research lack a test to check whether the result is accurate enough or not, although the validation with importing of real data is quite necessary. What’s more, considering the uncertainties during regional development, the system should be able to simulate by given scenarios under different conditions. However, the function is not available at current stage.

Although crude at this stage, the system allows for the simulation of effect of environmental policy on GHG emissions during the development of rubber city. We simulate the effect of policy by designing the decision process for agent behavior. In this way, the system is able to simulate the effect of policy on agent’s behavior, further on GHG emissions. By analyzing the result, the problems of the existing policy can be known. Meanwhile, the possible direction of setting future policy will be clear. In this stage, the advantage of agent based simulation approach has not been completely taken, more factors should be set to be closer to the actual behavior of agents. In addition, because the system cannot simulate different policy scenarios, the comparison of effectiveness for different policy is not available in this system.

Chapter 3 Agent-based Simulation of an Policy for Household Electricity Sharing in Smart Community

3.1 Introduction

After Fukushima crisis, Japan cut down the nuclear energy. As a result, the carbon emission in the 2012 increased by 9% compared with 1990(Ministry of the Environment, 2015). Recently more attention have been gained for the risk of nuclear power because of the nuclear accident, which make solar power energy to play a more and more important role as renewable energy source than before. The technology for home energy management in the most efficient way with the network is known as Home Energy Management System (HEMS), which allows connecting home appliances to the network for remote management based on the combination of the source network and Internet as saving system in real time. However, the use of renewable energy in demand side may cause difficult problems in the balance between electricity supply and demand. Therefore, policy concepts for energy management based on the new technology and method are constantly being proposed during recent years. Among the issues taken by the development of solar power management, how to improve the efficiency of solar energy use and meanwhile keep the balance between supply and demand sides is a very hot one. Because, the rapid development of PV system enhance the solar energy generation, however the different life routine of household takes the waste of electricity generate by PV system.

In this case, the policy concept of electricity sharing might become vital to improve the usage efficiency of PV generated electricity in community energy management. Electricity sharing is defined as renewable electricity transferring between households inside a community with the target of using solar power effectively and reducing electricity generation from general grid at community level (Rathnayaka et al. 2015, Yamagata 2015). For an individual prosumer, after normal consumption and charging batteries, the surplus electricity it generate will be transferred to another prosumer in the same community whose electricity generated from PV system and battery is not enough for covering its consumption. In this way, the total surplus electricity will be firstly consumed internally inside the community, which would able to avoid wasteful loss. It is widely considered to be the development trend of new energy system and energy management policy, the framework relies on a smart community consists of a control center and electricity prosumers. The control center take charge of controlling the electricity transmission and the prosumers can monitor their status by smart devices. The rapid development of IT and large amount of PV modules installed in detached houses provides the hardware basis for electricity sharing concept.

However, the conditions of actual communities are kaleidoscopic because the ratios of households with different life routine are not uniform. Different life routine means that households play different roles during the electricity-sharing process according to time. Further, the dynamic changes of household number in demand side and supply side significantly affect the effectiveness of sharing process. In this case, how much the electricity-sharing concept could improve the efficiency of electricity use become a hot issue for the planning of energy management in smart communities. Because a major premise for planners to decide whether implement the concept of electricity sharing policy into a real community is checking the potential effect of the policy concept on improving efficiency of PV-generated electricity use.

Agent-based model (ABM) have been proven to be a flexible and rich modelling framework that can serve as a testbed for analyzing new paradigms in the field of smart grids, such as demand response, distributed generation, distribution grid modelling, and efficient market integration (Ringler et al. 2016, Naus et al. 2015). It can deliver specific insights in how different agents in a network would interact and what effects would occur on a higher level (Ma et al. 2016), so ABMs have been widely used for planning support of community energy management. However, few researches focus on the simulation of electricity-sharing concept, especially the variation of individual energy consumption behavior and the ratio of households with different life routine are not paid much attention in the simulation of existing researches.

Therefore, we proposed an agent-based model in this research designed for simulating the effect of energy-sharing policy and attempt to investigate the effectiveness of electricity sharing concept for improving the energy use efficiency of PV generated electricity in a virtual smart community. We firstly simulated the demand side energy consumption of household and divided the households into 4 patterns by life routine according to the result. Then, we set the ratio of households for the virtual community and designed the interactions based on the description of electricity sharing policy in the related literature. As a novel contribution to current research, the effectiveness of electricity-sharing policy for improving the using efficiency of PV generated electricity for communities could be checked which is important for the further revision of electricity sharing policy. Moreover, we predicted that this agent-based model could also assist planners in finding out the most suitable community type for the implement of electricity-sharing concept.

3.2 Simulation of Energy Consumption for Households as a Prerequisite

The realizing of electricity sharing policy relies on the energy management system of household. The most important work of energy management system can be simply described as scheduling which kind of electricity (from general grid, generated by PV or discharge from battery) should be use in what time to satisfy the need of demand side. That means the process highly depend on the precise prediction of the value of demand side energy consumption. Without an accurate simulation for the electricity consumption of households, it is even impossible to simulate the energy demand or can be supply of households. Thus, it is obvious that the simulation of energy consumption of household is a prerequisite for simulating the electricity process.

3.2.1 *Modeling Considerations for Simulating Energy Consumption for Household*

In Recent years, an increment in the research woks about household energy management models has presented. Dittawit K and Aagesen FA presented a project called Power Matching City with 22 households equipped with heating systems and home appliances as dish washers and washing machines. The objective was to observe the electricity supply and demand in the network, based on market mechanisms, as well as time usage of home appliances. Some houses had photovoltaic energy and others wind energy. The software is based on an agent of algorithms called ‘Power Matcher’ that aims to enable the economically optimum operation of the device within the conditions established by the end user (Dittawit K Aagesen FA, 2013). On the other hand, the Agent-Based Home Energy Management System, integrates smart metering technologies, preferred users configuration and flexibility, use of external signals as the price for residential energy optimization, network loads and changes in the energy market. Energy management in real time is achieved through the interaction of smart meters with the network (via prices or market incentives), and with Home Energy Management Systems (Asare-Bediako B, 2013). Yu Z developed a dynamic optimization model for stochastic thermal conditions in loads of different features, and a predictive model. The optimization is subject to the power, cost and thermal dynamics, and operates on multiple time scales: detection, control and parameter estimation. On and off control units were implemented. Three types of controllable loads: Dynamic load, interruptible load, and non-interruptible load are considered. The possibility of integrating renewable resources such as solar panels is also considered. The System has a control center that receives information through interruption or control signals with sensors. Consumers take control decisions in real-time about energy usage (Yu Z, 2013).

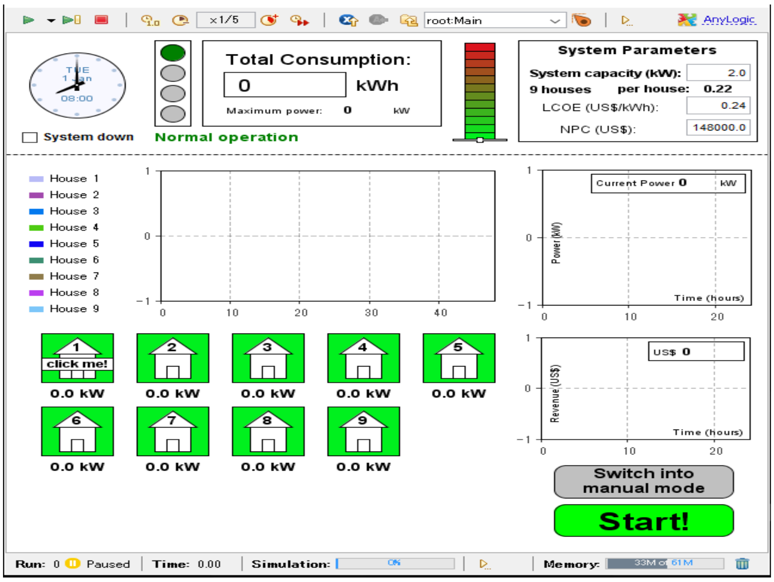
The traditional method used for the flow calculation of electrical network is based on static power flow calculations. These require the computation of a steady state of the network, and have to be rerun each time a change occurs if a continuous simulation wants to be executed. This can lay to a large number of re-calculations, leading to redundant steps, when only small changes affect small parts of the network. Implementing an agent based approach could try to solve these issues by providing more flexible and dynamic algorithms and through the combination of traditional and agent based modeling techniques. In the authors' opinion, agent based modeling is especially well suited to cope with all difficulties one finds trying to obtain a dynamic model of the energy consumption. The proposed model use the three central ideas of this paradigm: agents to represent households, the environment object to represent in space and time the geographic area where the power lines are wired, and then single rules are bring up to each agent in order to induce the necessary complexity to the model. Then, emergent properties of the model will represent the energy consumption behavior.

A conclusion can be drawn that the simulation of household energy consumption is a prerequisite of demand side energy management. Further, it's also an indispensable process for the research of residential energy optimization. However, the previous researches rarely consider the difference of household including the member composition, living conditions and lifestyle while simulating the household energy consumption. Besides, the energy management in urban community scale is also barely discussed due to the behavior of households with different types differs obviously which takes a difficulty for the simulation.

3.2.2 *Simulation of Household Electricity Consumption*

In this research, we use a model developed based on computational hybrid method and agent-based simulation approach to make a primary simulation of household energy consumption. The model is developed on the AnyLogic platform, although the model is just an initial one, a simple simulation of household energy consumption was conducted and we tried to make an exposition to the preliminary result. Further, by comparing with actual measured data, the simulation result was validated.

The interface of the model consists of 2 parts: main dash board and household interior. The number of households should be set in the beginning of the simulation. Then, the corresponding icon of households will generate in the main dashboard. During the simulation, the state of total energy consumption in whole community is monitored, and the system capacity which is the controlling condition of energy consumption can be adjusted at any time in the main dashboard. The electric consumption level of each household is presented by different colors in the main dashboard while the current load is shown simultaneously. By clicking the icons, users can get into the interior of household where the detail of household energy consumption is presented. For instance, users can understand the layout while also observe the operating status of appliances inside the house. Besides, the energy consumption of the selected household is also presented in the household interior as showed in figure-3. For each individual household, the interior layout can be preset and generally consist of several parts including bedroom, bathroom living area, kitchen and common room. What's more, the number and location of appliances can be also set manually according to the different conditions.



Total Consumption: 0 kWh
Maximum power: 0 kW
System Parameters
System capacity (kW): 2.0
9 houses per house: 0.22
LCOE (US$/kWh): 0.24
NPC (US$): 148000.0
Current Power 0 kW
US$ 0
Run: 0 Paused
Time: 0.00

Figure 3-1. Main dashboard interface

1) Load modeling: The modeling of loads can be a quite complex issue. The behavior of a load mainly relies on the electrical energy consumption created by an appliance. Considering a load in the traditional, electrical engineering sense, a single impedance with some fixed characteristics is meant. But regarding energy consumption, the connected loads normally will be households or some other complex consumers that consist of a large number of appliances that create an aggregated energy demand. In present version of the model, the following appliances are considered: lighting bulb (LED bulb, CFL bulb and Incandescent bulb), radio, TV, Computer, Fridge, washing machine, and phone charger. The model will simulate the operation of the appliances based on the possible behavior and position of the household members at that time point.

2) Energy consumption control condition: In the present version, the main control condition of energy consumption for the model is electricity peak. In beginning of the simulation, the tolerable total load of all households should be set as the limitation factor. Thus, during the simulation, if the total load is close to or exceed the set value, the system will determine there is high risk that Electric Peak happens and start a countdown to stop the simulation. The controlling process is shown in figure-4.

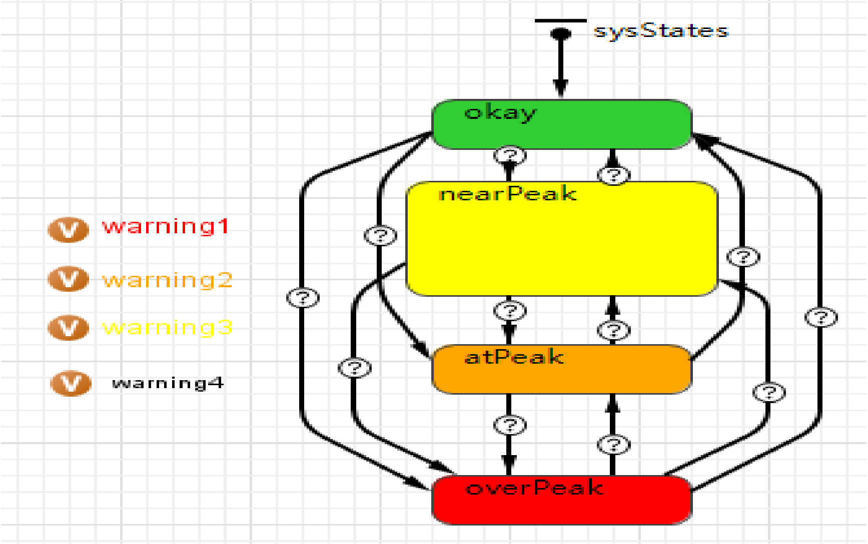


Figure 3-2. Controlling process for energy consumption

In present version of the model, we focus on the electric consumption inside individual household, thus we set up 1 household and operate a round of simulation to generate the result. According to the general case, the house is set as the typical form of Japanese apartment house, the layout including a kitchen, a living area, a bathroom (with toilet), and 2 bedrooms. The number and locations of the appliances is set based on the life experience by the Japanese style, the details are as figure-5 shows.

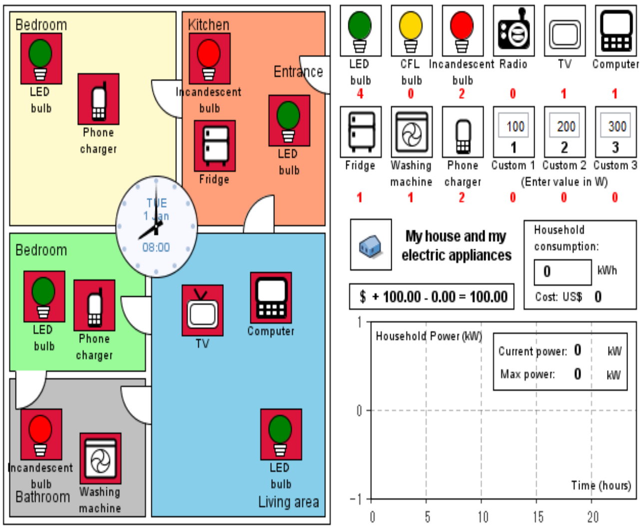
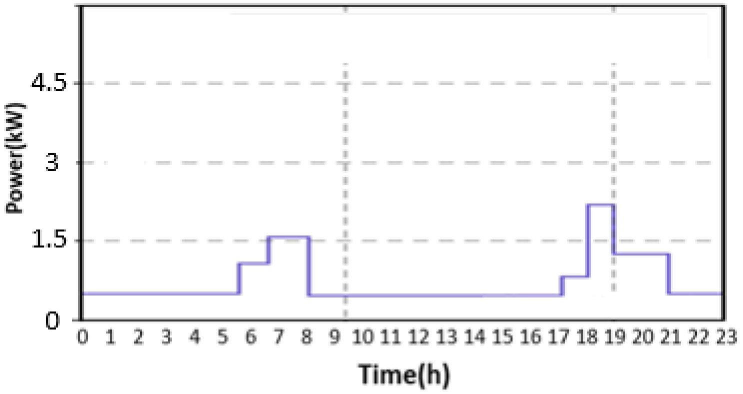


Figure 3-3. Household interface

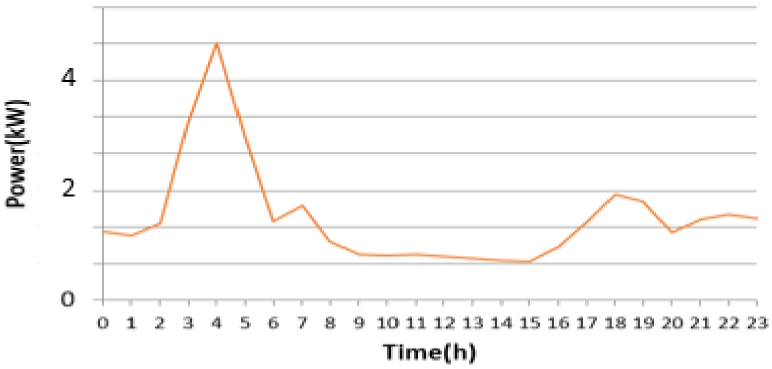
As for the simulating time, it is assumed to be an ordinary workday, the electric consumption of household for a whole day from 0:00 a.m. to 24:00 p.m. will be simulated. During the whole simulation, the Fridge kept operating because it is the only appliance that demands uninterruptible electric supply in the present version of the model. The hourly usage conditions of other appliances is listed in table 1.

Table 3-1. Hourly usage conditions of appliances except Fridge

Time	Appliances under operation
0:00~6:00	2 phone chargers
6:00~7:00	2 incandescent bulbs
7:00~8:30	incandescent bulb, TV
8:30~18:00	None
18:00~19:00	incandescent bulb, LED bulb
19:00~20:00	incandescent bulb, LED bulb, TV, washing machine
20:00~22:00	LED bulb, TV, PC,
22:00~24:00	2 phone chargers



(a)



(b)

Figure 3-4. The trend of electric consumption in simulation result (a) and actual measured data (b)

Figure-6 shows the simulation result of electric consumption trend comparing with the actual measured data. The curve represents an active power demand (almost no reactive power is consumed by households). As figure-6(a) shows, the value keeps stable and relatively low in most of the time, 2 peaks of energy consumption happened during the simulation. The peaks happened in the morning and evening as they coincide with the usage time of high power devices. Figure-6(b) shows the average electric consumption value of weekdays in Oct., 2015 of an ordinary office-worker household living in Osaka. A consumption peak happens from 2:00 to 6:00 because this household charge the storage battery with a cheaper price in midnight. Beside this, the trend of electric consumption in actual measured data is generally agreeable with the simulation result, which means that the result totally reflect the realities of ordinary Japanese office-worker households. All the members go to work or go to school in the morning and stay outside during daytime. After work, they go back home and start a series of complex activities inside house.

3.2.3 *Energy Consumption Curve of Household with Different Life Routine*

The household can be divided into different patterns according to their life routine (Zhengen Ren et al, 2013). The life routine means occupied period of the home for household, while as to the energy consumption, the different life routines lead to different consumption curves. In this research, we defined 4 life routine patterns for Japanese household according to the survey data in Annual Health, Labor and Welfare Report 2015 published by Japanese Ministry of Health, Labor and Welfare.

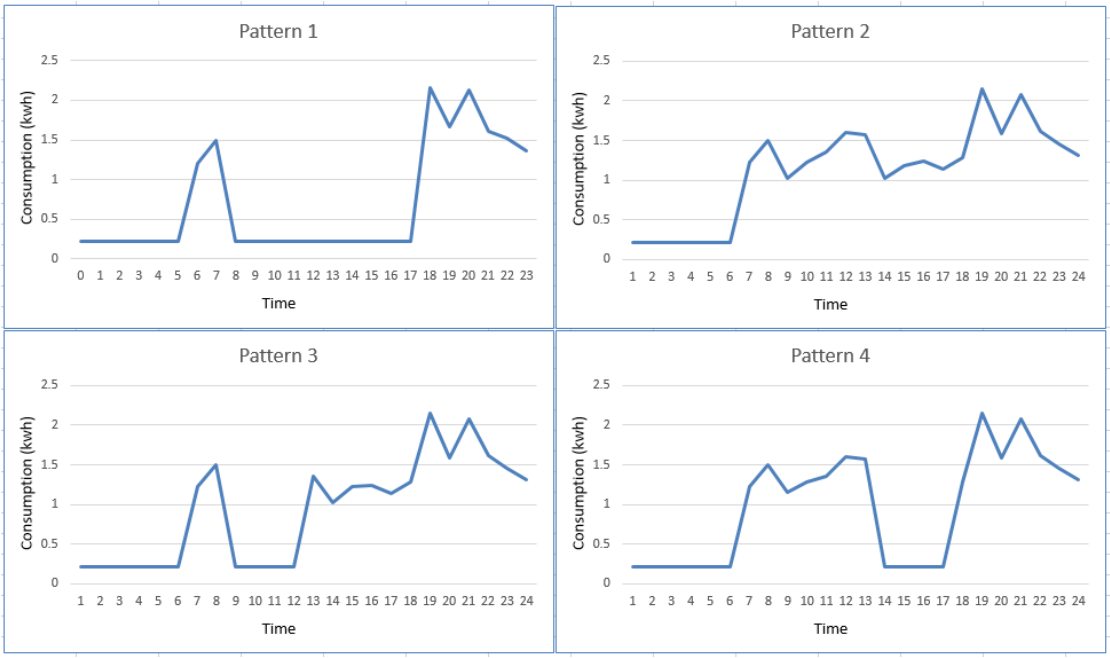


Figure 3-5. Household electricity consumption curves

Pattern 1: All occupants in the house have full-time jobs. In japan, more than 70% people who have full-time job are working from 7:00 to 17:00 in weekday. And the average commuting time of Japanese is 80 minutes per day which can be considered as each 40 minutes in the morning and in the evening. Thus, unoccupied period of pattern 1 is from 08:00 to 18:00.

Pattern 2: The house is occupied all the time. This type of household may have a housewife, or there may be occupants retired.

Pattern 3: Unoccupied period is from 08:00 to 12:00. One of the occupants in this type of household may have a part-time job in the morning session. And because most of part-time workers prefer to hunt part-time job near their house, the commuting time was not been considered.

Pattern 4: Unoccupied period is from 13:00 to 17:00. One of the occupants in this type of household may have a part-time job in the afternoon session.

We scheduled the appliances use of households as introduced in the previous section according to the Survey on Time Use and Leisure Activities 2015 conducted by NHK. After that, we simulate the energy consumption of the households with four different patterns, the results are as the following figures. The consumption curves will be set as the parameters of household agent in the ESS.

3.3 System Design for Simulating the Electricity Sharing Policy

3.3.1 *Description of Electricity Sharing Policy*

“Feed-in tariff” policy is now conducted in the Japanese smart communities. The “Feed-in tariff” policy encourage households transmitting the renewable electricity to general grid to get the payments from governments and utilities. However, because the renewable electricity generated by prosumers is firstly gathered into general grid then distributed again, the long distance transmission takes significant power loss together with additional costs. The concept of electricity sharing policy may solved such problems by improving the using efficiency of solar power generated by households inside community. Thus, although electricity sharing policy has not been conducted in Japanese smart communities yet, it is widely considered to be the developing trend of renewable energy management policy for smart communities. According to the existing research, Electricity-sharing is defined as direct PV generated electricity transmission between households inside a community with the target of using solar power effectively and reducing electricity generation from general grid at community level(Rathnayaka et al, 2015). In this research, while we define the rules of electricity sharing, we referenced the current policy of electricity sharing in European countries. The main rules of electricity sharing policy concept in this research are listed as follow:

- The electricity generated by PV system can be transmit between households inside community.
- After the electricity consumption, the surplus electricity will firstly charge the storage battery then share electricity to other household in every hour.
- If the PV-generated electricity is not enough for covering the energy consumption in this hour, the electricity in battery will be consumed in priority to shared electricity.

- In normal situation (no disaster or energy crisis), the electricity in battery will not be shared.
- The shared electricity should not be used for charging the battery.

3.3.2 *Simulation of Electricity Sharing Process*

In this research, a virtual community is defined based on the conditions of smart community in Japan. In this virtual community, there are two kinds of agent: household agent and control center agent. It is assumed that all of the household agent are equipped with PV system. They consume electricity for normal life meanwhile generate electricity by solar power via PV system. In the other hand, control center agent take charge of energy management of the community including the electricity sharing process. The interface of system is showed in the following figure, the control center agent locates in the center parcel of the virtual community, while the households randomly locate in the virtual community. The color refer the state of household agent in this stick, green means the household can supply electricity to other household, and the red means household demand more electricity for normal life. The rest grey household agents keep electricity balance in this tick. What's more, the lines with arrow denote the transmitting directions of PV generated electricity.

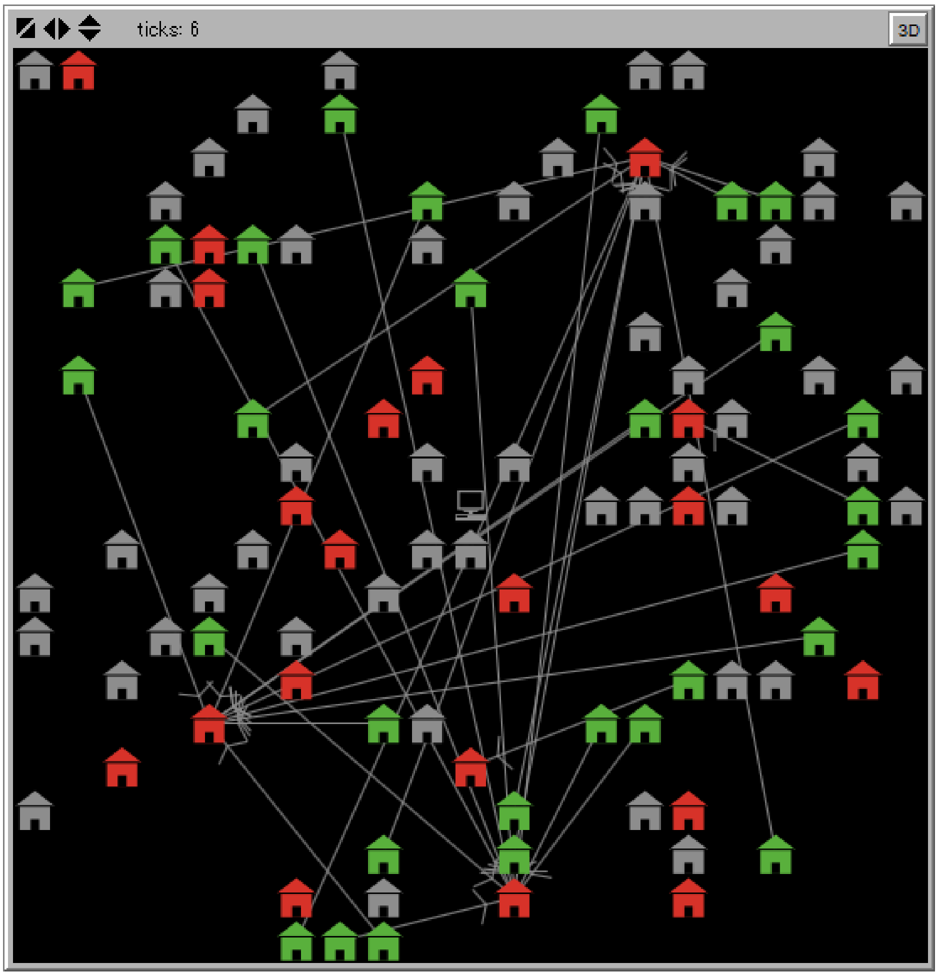


Figure 3-6. Interface of ESS

The electricity sharing is defined as a new interaction between household, and conducted via the behavior of household and government. The whole simulating process is showed as following figure.

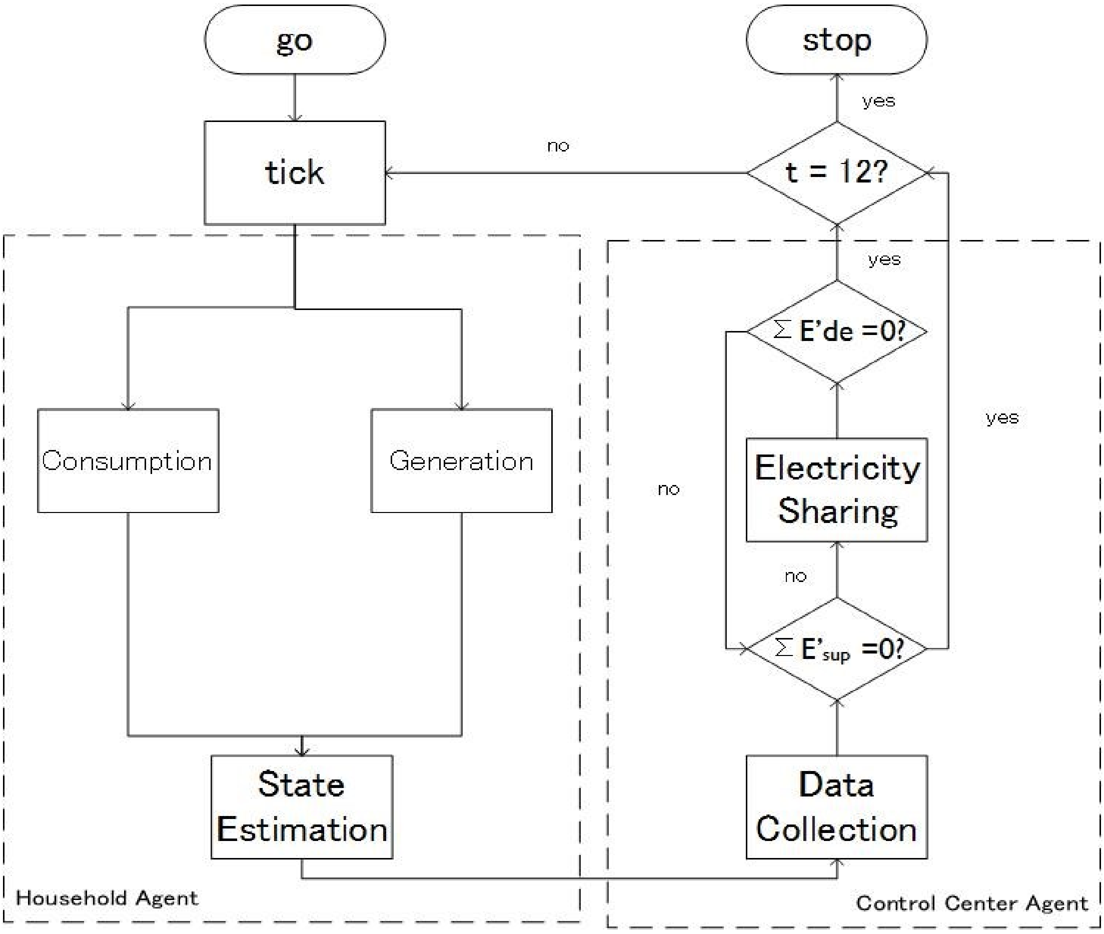


Figure 3-7. Flow chart of simulation process

In every ticks, the household agent will start the consumption behavior according to their pattern as introduced in previous section. Meanwhile, the electricity will be generated by PV system. In this research, it is assumed that the PV generated electricity positively correlates with the sunshine and the sunshine is from 6:00 to 18:00 during the simulation. Moreover, the sunshine will be strongest in 12:00. Thus, the PV generated electricity of household agent can be calculated by following equation:

$$E_g = E_{gmax} - \frac{Egmax}{36}(t-12)^2$$

Where,

E_g: PV generated Electricity

E_{gmax}: PV generated Electricity when time = 12

t: time in the simulation

After consumption and generation, the household agent will start a state estimation module to judge whether it can supply electricity or it demand electricity by following equations.

(1) if $E_g > E_c$, *ask* $E'_{de} = 0$,

when $E_{bmax} - E_b \geq E_g - E_c$

$\Delta E_b = E_g - E_c,\ E_{b(t+1)} = E_b + \Delta E_b,$ State: Balance

when $E_{bmax} - E_b < E_g - E_c$

$E'_{sup} = E_g - E_c - \Delta E_b,\ E_{b(t+1)} = E_{bmax},$ State: Supply

(2) if $E_c > E_g$, *ask* $E'_{sup} = 0$

when $E_b \geq E_c - E_g$

$\Delta E_b = E_c - E_g,\ E_{b(t+1)} = E_b - \Delta E_b,$ State: Balance

when $E_b < E_c - E_g$

$E'_{de} = E_c - E_g - E_b,\ E_{b(t+1)} = 0,$ State: Demand

(3) if $E_c = E_g$, State: Balance

Where,

E_c: *Electricity Consumption*

E'_{de}: *Electricity Demand*

E'_{sup}: *Possible Electricity for Supply*

E_b: *Electricity in Battery*

E_{bmax}: *Max Electricity of Battery*

ΔE_b: *Electricity charged into Battery in this hour*

The control center agent will firstly collect the data for household agent and summary the $\sum E'_{sup}$ and $\sum E'_{de}$ of households. If $\sum E'_{sup} > 0$ which means there is electricity can be supply in the community, the electricity sharing process will be started and it will continued several turns until the $\sum E'_{de}$ become 0 which means all the demand of electricity have been satisfied or $\sum E'_{sup}$ become 0 which means there is no more electricity can be shared in the community. In each turn, the control center agent always ask household with max E'_{sup} transport electricity to household with max E'_{de}. At the end of every turn, $\sum E'_{de}$ and $\sum E'_{sup}$ will be calculated again for the judging process mentioned above. The matching rule of household with supply and demand state can be descripted as follow equations.

In turn i

If $E_{sup}{}' \geq E_{de}{}'$

$\Delta E = E'_{de}$

$E'_{\sup(i+1)} = E'_{sup} - \Delta E$

$$\text{If } E'_{sup} < E_{de}{}'$$

$$\Delta E = E'_{sup}$$

$$E'_{\mathrm{de}(i+1)} = E'_{de} - \Delta E$$

For each household:

If state = supply

$$E_{sup} = \sum_{1}^{i} \Delta E$$

If state = demand

$$E_{de} = \sum_{1}^{i} \Delta E$$

Where,

ΔE: energy shared in turn i

E_{sup}: total electricity supplied till turn i

E_{de}: total electricity received till turn i

3.4 Simulation Result

3.4.1 *Initial Parameters*

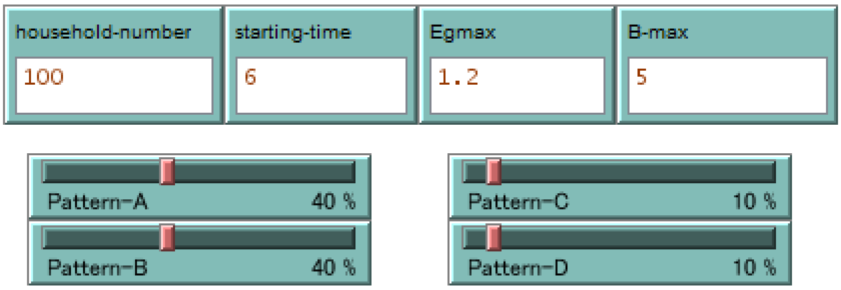
In this research, the initial parameters of simulation include starting time, household number, ratio of household with different pattern, max PV generator output and Battery capacity. It is assumed that the sunshine in the virtual community is from 6:00 to 18:00, so the starting time will be set as 6, and the simulation will be end in 18:00 pm in the virtual community. For achieving a relatively large sample size, another assumption is made that the virtual community consists of 100 household. Thus the household number will be 100. According to the Labour Force Survey 2017 conducted by Japanese Ministry of Internal Affair and Communications, we set the ratio of household with different pattern as 40% for pattern 1, 40% for pattern 2, and both 10% for pattern 3 and pattern 4 in perspective.

As to max PV generator output and battery capacity, we collect the parameters of popular PV systems, and summarized as following table. Based on the data in the table, we set the max PV generator output to be 1.2 kW/h, meanwhile the Battery Capacity of households to be 5kWh in the virtual community.

Table 3-2. Summary of max PV generator output and battery capacity of PV systems

Manufacturer	Type	Max PV generator output (kW/h)	Battery Capacity (kWh)
Denso	DNHCLB-AHW4	1.2	4.1
Sharp	JH-WB1201	1.3	4.8
DigiReco	ELE-CUBE SP-4800	1	4.8
Panasonic	LJ-SF50A	1.2	5
NEC	ESS-H- 002006B	1.5	5.5
Sony	ESSP-30 05/18P	1.2	6
Eliiy Power	POWER iE 6	1	6

In summary, the value of initial parameters are as showed in the following figure.



household-number 100

starting-time 6

Egmax 1.2

B-max 5

Pattern-A 40 %

Pattern-B 40 %

Pattern-C 10 %

Pattern-D 10 %

Figure 3-8. Initial parameters of ESS

3.4.2 *Result and Discussion*

We repeated the simulation 30 times and calculated the average value as the simulation results of this research. The following figure shows the result.

Table 3-3. Simulation result of ESS

time	*total consumption*	*day consumption*	*Epv potential*	*day Epv potential*	*actual Epv used*	*day actual Epv used*	*internal use*	*day internal use*	*electricity shared*	*day electricity shared*
6	120	120	0	0	0	0	0	0	0	0
7	150	270	36.67	36.67	36.67	36.67	36.67	36.67	0	0
8	63.4	333.4	66.67	103.34	66.67	103.34	61	97.67	5.67	5.67
9	73	406.4	90	193.34	79.67	183.01	72.67	170.34	7	12.67
10	79	485.4	106.67	300.01	85.67	268.68	81	251.34	4.67	17.34
11	91	576.4	116.67	416.68	97.67	366.35	86	337.34	11.67	29.01
12	100.9	677.3	120	536.68	103.96	470.31	94.13	431.47	9.83	38.84
13	62.5	739.8	116.67	653.35	77.7	548.01	77.7	509.17	0	38.84
14	70.5	810.3	106.67	760.02	79.63	627.64	78.33	587.5	1.3	40.14
15	73	883.3	90	850.02	82.13	709.77	70	657.5	12.13	52.27
16	68	951.3	66.67	916.69	66.66	776.43	58.33	715.83	8.33	60.6
17	85.6	1036.9	36.67	953.36	36.67	813.1	32.4	748.23	4.27	64.87
18	216	1252.9	0	953.36	0	813.1	0	748.23	0	64.87

The total electricity consumption of the simulation is 1252.9kWh, the total potential of PV in the simulation is 953.36kWh while 813.1kWh is actually consumed by households in the simulation. Amon the PV generated electricity that actually been used by household, 748.23kWh of electricity is for internal use which means this part of electricity was not been shared. On the other hand, the day total electricity shared is 64.87kWh, for a better understanding, we listed the matrix of sharing times for household with different pattern in following table.

Table 3-4. Matrix of sharing times for household with different patterns

Supply	Demand			
	Pattern 1	Pattern 2	Pattern 3	Pattern 4
Pattern 1	0	273	20	47
Pattern 2	0	0	0	0
Pattern 3	0	27	0	13
Pattern 4	0	40	30	0

What’s more, the electricity shared at each hour is as following figure showed.

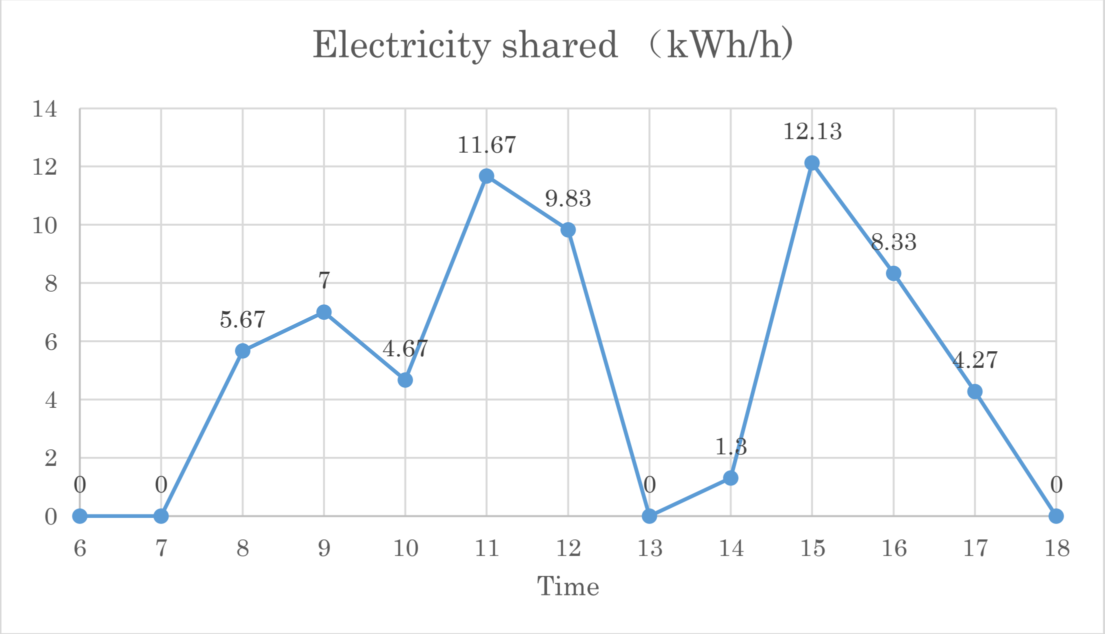


Figure 3-9. Electricity shared in every hour

There are two peaks of electricity sharing in the simulation, appeared at 11:00 and 15:00. While at 13:00 and 14:00, the value of electricity shared is relatively low, which caused by the peaks of electricity consumption. The household of pattern 1, totally supplied electricity 340 times and didn’t demand any electricity from other patterns. They worked as pure producer of PV generated electricity in the implement of electricity sharing policy. On the contrast, Pattern 2 are complete consumers during the electricity sharing process. They didn’t supply any electricity during the simulation. As to pattern 3 and pattern 4, the situations are relatively complex, they both supply and demand electricity during the simulation.

The comparison of day potential PV generated electricity, day actual PV generated electricity use, day internal use of PV generated electricity and day electricity share is shown in following figure. We can find that the internal use take 78.48% of potential PV generated electricity, while the actual use takes 85.29%. Thus, a conclusion can be drawn that the electricity sharing policy improved 6.81% efficiency of PV generated electricity use for the virtual community.

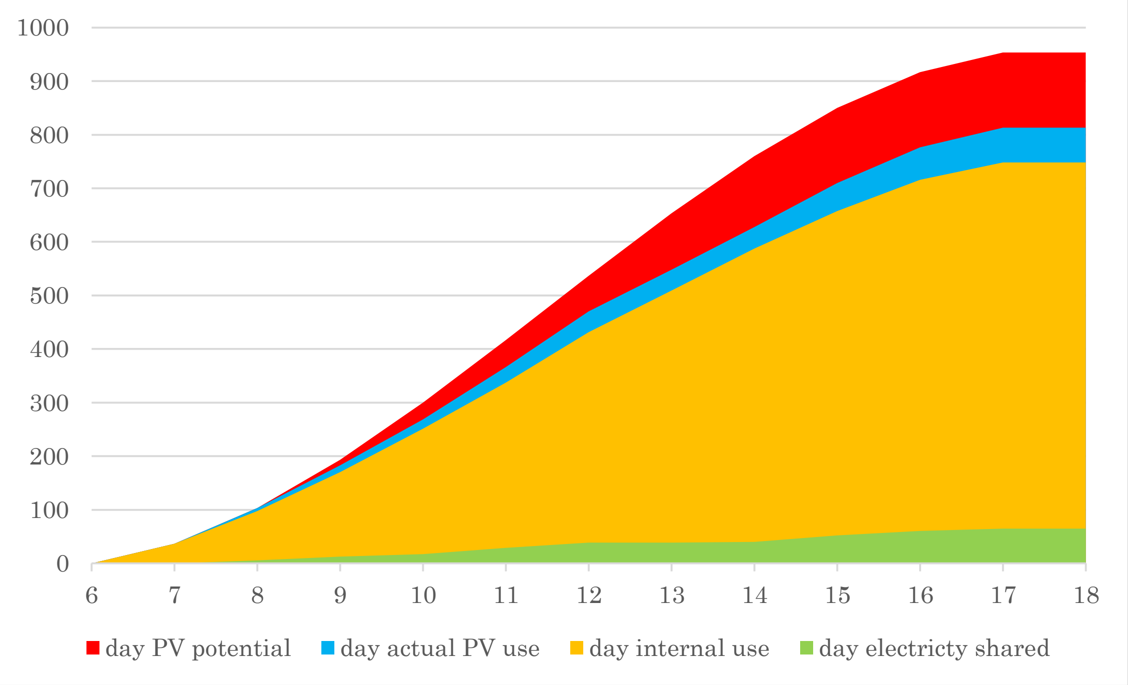


Figure 3-10. comparison of PV potential, actual use, internal use and electricity shared

3.5 Conclusions for this Chapter

In this chapter, we introduced a policy concept named electricity sharing that targets to improve the efficiency of using PV generated electricity by let households share surplus PV generated electricity with others. To prove the effectiveness of electricity sharing policy, firstly the energy consumption behavior of household with different life routine patterns should be simulated, then the electricity sharing process should be created based on the rule in electricity sharing policy. For the first part, we used a model developed on AnyLogic platform to make simulation of household energy consumption based on the different life routines. For the second part, we developed an ABS system named ESS consist of a virtual community as environment, household agents and a control center agent. In ESS, electricity sharing is set to be an interactions between household agents. Regarding to the situation In Japan, in order to present efficiency change of using PV generated electricity resulted from the implement of electricity sharing policy, we collected the PV system related data and designed the parameters of the PV system for household agent in the virtual community. Moreover, the ratio of household with different patterns is set according to the Labor Force Survey 2017 conducted by Japanese Ministry of Internal Affair and Communications. As result, the electricity sharing policy improve 6.81% using efficiency of PV generated electricity for the virtual community, which means that the electricity generated from general grid reduced 64.87kWh, That equals to around 32.43kg CO_2 reduction.

Although the ESS is able to simulate the effect of electricity sharing policy, there are still many things that we have not fulfilled in this research. For example, the life routines of household are not exactly follow the patterns we defined in this research, such as the retired people may also have some outdoor activities instead of just stay at home. Within this process random has been used to reflect the different electricity consumed by each household. While the random distribution has not been analyzed in this research. Furthermore, all of the PV systems are set to follow the same standard in the system. However, in the real case, the parameters of PV system such as max output and battery capacity are different according to the situation of each household. Meanwhile, the impact of weather change on energy generation has not been considered in the system. Instead, we just assume that it is a sunny day with the sunshine from 6:00 to 18:00 and the solar generation follows a theoretical equation.

While all these limits do not mean our research is meaningless or unreasonable, the energy sharing interactions is designed completely based on description of the rule in energy saving policy, so that the simulation presented sharing process well. Thus, the result is reasonable for showing the effect of electricity sharing policy on improving using efficiency of PV generated electricity. Meanwhile, as shown in the previous section, the ratio of household with different life routine patterns can be set as initial parameter for the simulation, the different community can be totally simulated by our system and hereby supports to government decision-making on implement the policy for specific community or not.

Chapter 4 Agent-Based Simulation of the Effects of an Environmental Tax Policy on Residential Gas Use and CO2 Emissions

4.1 Introduction

To pursue a sustainable society which achieves low-carbon society, in the fourth environmental basic plan, it indicates that 80% of the greenhouse gas emission should be reduced before 2050 in Japan (Ministry of the Environment of Japan, 2012). In the tax system reform in 2012, the tax for global warming policy was established which includes the energy taxation. With this background, the Kanazawa water and energy center added the environmental tax to the gas price as a respond to the global warming countermeasure from the aspect of fossil fuel. The environmental tax policy on residential gas in Kanazawa city implements with three steps: The first step is from the April in 2013, and the second step is from the April in 2014, the third step started from the October of 2014. In each step the gas price was increased by 0.21 yen per cubic meter of gas consumption. Thus, the unite price of gas are increased as Table 4-1 showed.

Table 4-1. Unite gas price change by the environmental tax policy

	Before 2013.04	**2013.04-2014.04**	**2014.04-2014.10**	**After 2014.10**
Unite gas price(yen)	P_{original}	$P_{\text{original}} + 0.21$	$P_{\text{original}} + 0.42$	$P_{\text{original}} + 0.63$

When it comes to the research of environmental policy effects, there are mainly three kinds of method applied in recent years: researches based on survey data, researches based on statistic data and researches based on models. Researches based on survey data usually has some relationships with the consuming behavior. Schaffrin et al conducted an investigation of energy practices of different social groups to verify the effectiveness of policies targeting household energy conservation based on the survey data of Denmark, Austria and UK (Schaffrin et al, 2015). Mats Bladh and Helena Krantz studied the energy saving behaviors in residential sectors using metered data of a large sample and interview data with a small sample (Mats Bladh and Helena Krantz, 2008). As it needs to make the investigation and collect data, it also need a long period of time. Moreover, the cost of investigation is also higher comparing with other methods.

Most researches based on statistic data are conducted by applying the data to some mathematic models. Ghosh et.al compared the efficiency, distributional and emission leakage effects of border tax adjustments as port of unilateral climate policies by CGE model with statistic data (Ghosh et.al, 2012). With statistic data, researches could be done in a large scale. Rocchi et.al analyzed the potential economic impacts of the reform of European energy tax directive using statistic data of 27 counties in Europe (Rocchi et.al, 2014). The limitations of researches based on statistic data includes the hidden of heterogeneous of individuals and limitations on variable control, which may lead to the deviation when explaining the result.

Researches on energy policy models have sprung up in recent years. Galinato et.al simulated an integrated tax-subsidy policy for carbon emission reduction in the electric power and motor fuel industries (Galinato et.al, 2010). However, with an overview of the researches based on energy policy model, little attention has been paid to model the impacts on households' behavior (Motawa I and Oladokun M, 2014).

Agent-based simulation has been improved effective with policy research with heterogeneous behaviors. Yan Ma et al simulated a residential promoting policy effects on downtown revitalization using an agent-based household residential relocation model (Yan Ma et al, 2013). Jordan R et al created an agent-based model of residential mobility and simulated the impacts of a specific urban regeneration intervention (Jordan R et al, 2014). As a bottom up simulation, agent-based simulation has the advantage of modelling the behaviors of heterogamous individuals. Meanwhile, it has the function of creating interactions between agents, which made it possible to model the decision making process with many variables especially for the individuals in a community. For example, Chen Ping et al simulated the decision making process of household choosing a shop considering the distance, the price, the shop facility conditions (Chen Ping et al, 2006).

The objective of this research is to develop an agent-based model with heterogamous gas consuming behaviors to assess the Environmental Tax Policy in Kanazawa city. As an agent-based model, it will pay more attention on household energy consuming behaviors comparing with other researches. In addition, to make the model closer to the real case, the interactions between agents is also a key point, which is rarely seen in the simulation of environmental policy effects. The simulation in different scenario is conducted to compare the environmental tax policy with other possible policy for reducing residential gas consumption and GHG emissions.

4.2 System Design for Environmental Tax Simulation

4.2.1 *System Framework*

The System framework with Netlogo platform mainly includes two parts: the interface and the procedure. The user could give instructions and view the simulation results through the interface. The designed model is programmed on Netlogo, which is described as procedure in the system framework. The UML class diagram of ETS is shown in Figure 4-1, which could explain the system framework intuitively.

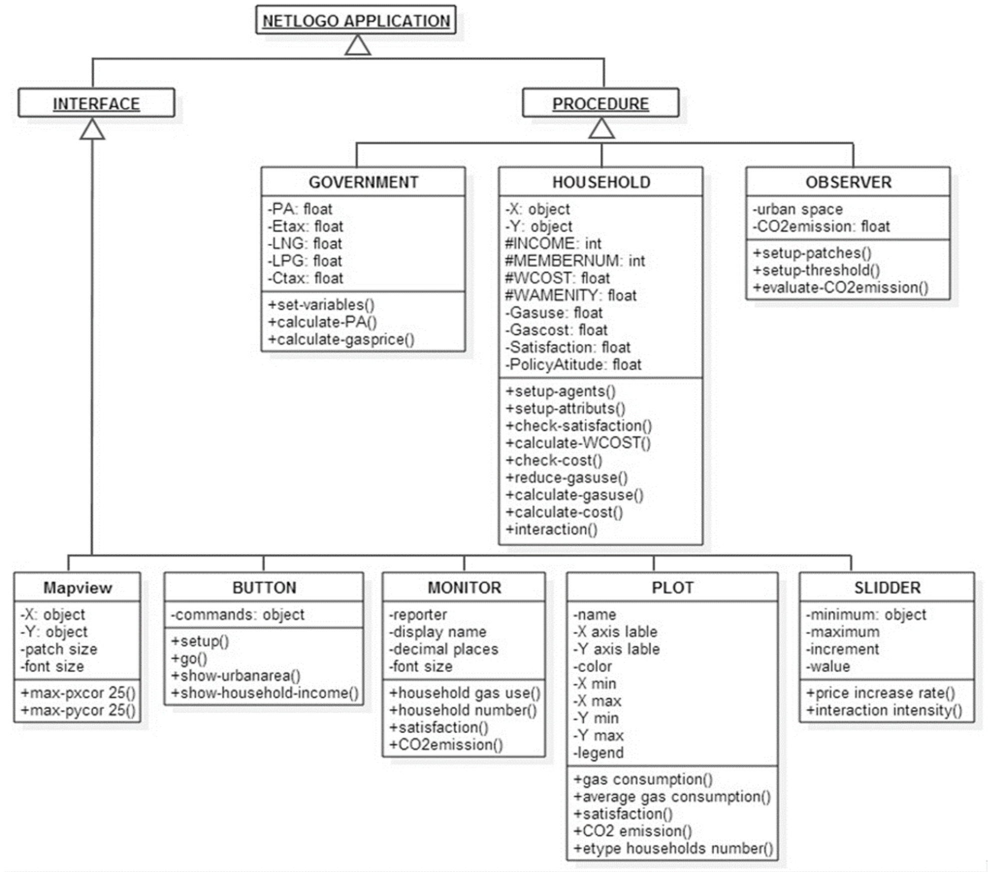


Figure 4-1. UML class of ETS

4.2.2 *Environment, Agent and Interaction*

The environment of the ETS is a virtual city that follows basic characters of Kanazawa City. All the household agents in the simulation system are located in the virtual urban space according to the real case (Yan MA et al, 2013). In the virtual city, there are there kinds of land zone: the CA (center area), the UPA (urban promotion are) and the UCA (urban control area). The 1500 households are located in the urban space, as shown in Figure 4-2.

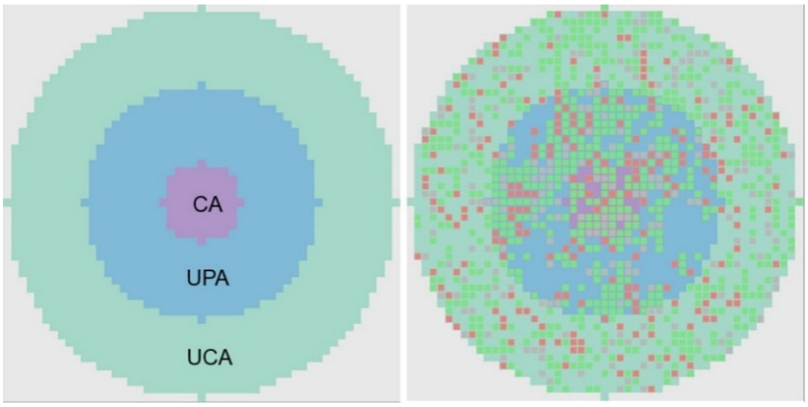


Figure 4-2. UML class of ETS

There are two kinds of agents in the ETS: the government agent and the household agent. The government agent supposed to set the price of the gas and also it is the agent conduct the Environment Tax policy. There are only one government agent in the system. The household agent is divided into three groups by income, different income group will have different behavior of gas consuming. 1500 household agents are set in ETS with their own attributes. The attribute of government agent and household agent are shown in Table 4-2.

Table 4-2. Attribute of agents

Agent type	**Attribute**
Government	BU(bas unit price), BP(base price), PA(price adjustment), CT(consumption tax), ET (environment tax)
Household	Location, Income, Member, WCOST(want to cost), WAMENITY(want amenity), Gas use, Gas cost, satisfaction, policy attitude, communication chance.

In ETS system, the interactions between agents can be concludes into two type. One is the interaction between government agent and household agents. The government set the energy price system and make change on it, the price change will influence the households' behavior of energy consuming. While the government also has some targets about the energy use, for example to reduce CO2 emissions. This will make the government investigate the effects of the policy on the households. Thus, for the households, they also influence the decision making of the government by their behavior of energy consuming. Another interaction is between households agents. Obviously, in real case, households communicate during their daily life, and the communication will leads to changes of their behaviors. In ETS, the interaction between agents are set according to their location, which means the households live next to each other are more likely to communicate. Specifically, the interaction between households is the communication about the energy price and tips of energy saving. The interaction intensity which means their communicating chance is different according to different kinds of household agents. The detail of the interaction will be introduced in the following part.

4.3 Behavior and Interactions Design for simulating the Effect of Environmental Tax Policy

4.3.1 *Government Behavior*

The behavior of government agent in ETS includes two parts. Firstly, the government set the gas price system in the virtual city and calculate the gas price for each household agent in every tick. Secondly, the government agent will conduct the environmental tax policy as the Kanazawa water and energy center introduced.

The government agent calculate the gas price for household agent by following equation which we referenced from the tiered gas pricing system as Kanazawa water and energy center implements.

$$GC = [BP + (BUP + PA + ET) \times C] \times (1 + CT)$$

Where,
GC: Gas Charge　(ガス料金)
BP: Base Price　(基本料金)
BUP: Base Unit Price　(従量料金単価)
PA: Price Adjustment　(原料費調整額)
ET: Environmental Tax　(環境税：地球温暖化対策のための税)
C: Gas Consumption　(使用量)
CT: Consumption Tax　(消費税)

The Price Adjustment is calculated based on the “Fuel Cost Adjustment System”. The Consumption Tax is 0.05 before April.2014, after that it become 0.08. The Base Price and Base Unite Price are different according to the gas consumption. As the information from Kanazawa water and energy center website shows, the Base Price and Base Unite Price are listed in Table 4-3.

Table 4-3. Base Price and Base Unit Price of gas in Kanazawa

Gas Consumption	Base Price	Base Unit Price
~ 10m^3	620 yen	226.75 yen
11 ~ 20m^3	640 yen	224.75 yen
21 ~ 60m^3	890 yen	212.25 yen
61 ~ 130m^3	1000 yen	210.42 yen
131m^3 ~	1650 yen	205.42 yen

The government implement the policy by increasing environmental tax of gas consuming as shown in the previous section. For the behavior design of government on the policy, it makes changes upon the gas charge system narrated above. Applying to the simulation behavior design, it is set as the following equation.

$$ET = \begin{cases} 0\,, & t < 7 \\ 0.21, & 7 \leq t < 19 \\ 0.42, & 19 \leq t < 25 \\ 0.63, & t \geq 25 \end{cases} \qquad eq.2$$

Where,

t: "tick" in the simulation, it represent the "month" of the real case

4.3.2 *Gas Consumption Behavior of Household Agent*

The households' behavior is designed according to the literatures about households' gas consuming behavior. Because of limited research condition, surveys like questionnaire survey hasn't been conducted in this research. To remedy this limitation, a literature review on households' energy consuming behavior has been done. The results of some other researches are used as the theoretical support for the design of gas consumption behavior. There are many kinds of policies for affecting households' energy consuming behaviors, such as policies on propaganda or education, policies on economic and so on. The main energy policies with different method and the related information are summarized in Table 4-4.

Table 4-4. Energy Policies on Households with Different Methods

Method	Content	Effect	Researches
Education	Promote the awareness	Need long time, but have a lasting effect	Steg L, 2008[20] Darby S, 2006[21]
Economic	Adjust the tax, provide subsidies	Need short time, but the policy need to be updated continuously	Egmond C, 2005[22]

Method	Content	Effect	Researches
Technology	Provide the production of low energy cost	Need short time, have a lasting effect, but have limits on the technology progress	Watson J, 2008[23] Papachristos G,2015[24]
Laws and administration	Setup standards, limitation of emission	Need short time, have effect in a short or medium period. But only basic effects	Sovacool B J, 2009[25]

To summary, the technology method depends much on the technology progress and it need financial supports. The Laws and administration method only have some basic effect on energy consumption. For the individuals, Dwyer et al suggested, the economic saving have more effects compared with better awareness education (Dwyer et al, 1993). For households' energy consuming, it has shown financial resources (income) to be a major determinant for energy use (Bartiaus et al, 2011). Households with high income use more energy to achieve a more resourceful lifestyle which low income households tends to use less "unnecessary energy". That proves different income groups behave differently with policies related to energy price. Researches showed that households with high income is less sensitive to the energy price, meanwhile the price change may challenge the households with low income, who may face energy poverty (Wall and Crosbie, 2009). It also different a lot when coping with the increased energy price, it suggested that high income households tend to improve energy efficiency, such as buying energy efficiency appliances, while low income households tend to reduce the overall energy use. In addition, there is also energy use difference with different household type, households with people staying at home tend to spend more energy than households with all member working out (Schaffrin A, 2015). For the case in Japan, the government encourage households to reduce their energy use in many ways. From the "Katei Daijiten 2012", which is a guidebook of telling people how to reduce the energy use, the Japanese government suggested 6 ways to save gas use, it is used for designing the gas saving behaviors in this research. (Japanese METI, 2012).

Because of limited data, some assumptions have been made and mainly include:

(1) Although there are many kinds of policies related to energy consumption behavior in real society, it is assumed that only environmental tax policy have effects on gas consumption behavior of household agent in the ETS.

(2) In real case, the behaviors related to energy price are determined by many factors such as the income, the members in the households, the education levels of the

households and so on. In this research it is assumed that income is the most important factors.

(3) As there is no survey about energy saving behaviors of households in Kanazawa city, the behaviors are designed according to the literatures about different behaviors with different income, and the energy saving method provided by Japanese METI. The assumed gas saving behaviors are listed in Table 4-5.

Table 4-5. Gas Saving Behavior Assumptions

Item Number	**Content**	**Maximum Gas Saving Volume**	**Assumptions of Max Gas Saving ***	**Assumptions of Max Satisfaction Decrease ****
1	Wash the dishes using water with lower temperature	8.8 m^3/ year	4%	5%
2	Cook the food with microvan instead of using gas	9 m^3/ year	4%	1%
3	Wash the pot or pan often to clean the dust on them	2.38 m^3/ year	1%	1%
4	Take the bath one by one without interval times in a family	38.2 m^3/ year	18%	5%
5	Save the water when taking shower instead of making the water run out all the time	12.78 m^3/ year	5%	5%
6	Wash the dishes with hands instead of machines.	81 m^3/ year	39%	10%

*) It is calculated based on the average gas consumption of households in Kanazawa of a year

**) It is assumed based on the inconvenience level of each item

For different income group, they will select the different method of gas saving, the possible methods of each income group are listed in Table 4-6.

Table 4-6. Possible Gas Saving Methods of Each Income Group

Income Group	**Possible method (item in Table 5) and Max possibility of choosing the method***
Rich	2 (100%); 3 (100%); 5 (50%)
Middle	1 (50%); 2 (100%); 3 (100%); 5 (50%)
Poor	1 (100%); 2 (100%); 3 (100%); 5 (100%)

*) The possibility assumption is made based on living experience

(4) It is assumed that gas use of households with different income group in the virtual city followed the national survey (Schaffrin A et al, 2015).

(5) Satisfaction is a parameter to monitor the phenomenon of energy poverty. However, no mathematical model on relationship between gas use and satisfaction has

been found, thus, in this research, it is assumed the gas use and satisfaction has a positive correlation.

(6) There are mainly 3 purpose of gas use in Kanazawa city: cooking, boiling water and heating. As there is no data about households using gas for heating, and it is known from living experience that the households using gas for heating takes a small percentage in Kanazawa. Thus it is didn't considered in this research.

Based on the assumptions above, we designed the gas consumption behavior as following figure shows. At every tick in the simulation, the household will check his satisfaction first, if the gas consumption is under the basic satisfaction threshold, it will just keep the gas consumption of the basic consumption. If not, it will check the cost for the gas, if the cost is less than the money he wants to pay, it will just keep the gas consumption without any change. If else, the household agent will try to reduce the cost. For the part of gas reduction, it is suggested that there are two ways for gas reducing, one is to reduce the overall gas use, another one is to improve the gas using efficiency, and the way households choose is based on their income. The poor household is more likely to choose to reduce the overall gas consumption, while most of rich household will choose to improve the gas using efficiency. After the process of gas reduction, they will calculate their satisfaction and cost for the next tick. All the gas consumptions will be used in the CO_2 emissions calculation.

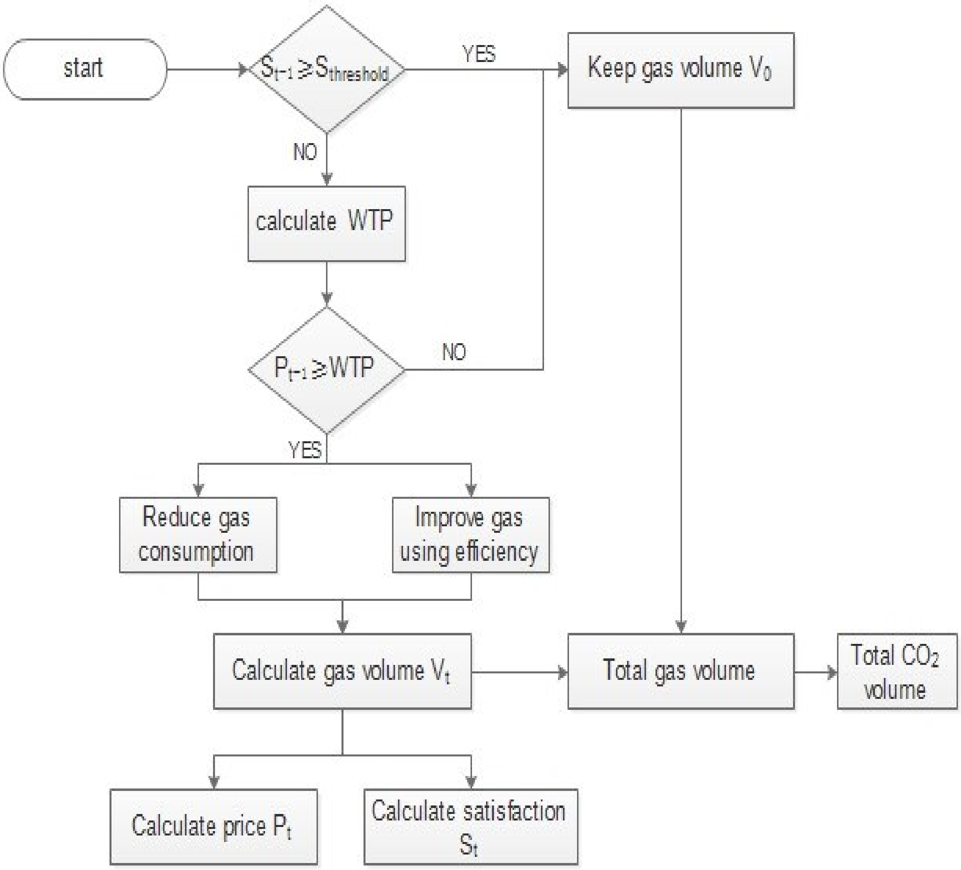


Figure 4-3. Gas consumption behavior of household agent

4.3.3 *Interactive Behavior of Household Agent*

As the existing researches suggested, there are interactions between households that affect the gas use for each other. Meanwhile, according to description of environmental tax policy, it mentioned the tax will be used for improving the environmental education which can be considered as enhance such interactions between agents. Thus, we designed the interactive behavior of household agent in the ETS by creating interactions between household agent of communicating gas price and gas saving tips. As following picture shows, at every tick in the simulation, household agent will first check the number of members. As related research suggest, households with more than 1 people are more likely to have the interactions with other household. Thus in this model, if the household contains only 1 member, there will not be any interactions. Then, household will divide into 2 types: the e-type household and the non-e-type household, which is based on whether they have conducted gas saving behavior. The e-type households are thought knowing the tips for saving gas and will influence their neighbors with non-e-type. After the interaction, the non-e-type household may reduce their gas consumption, if they reduced their gas use more than 4.5%, will turn into the type of e-type household.

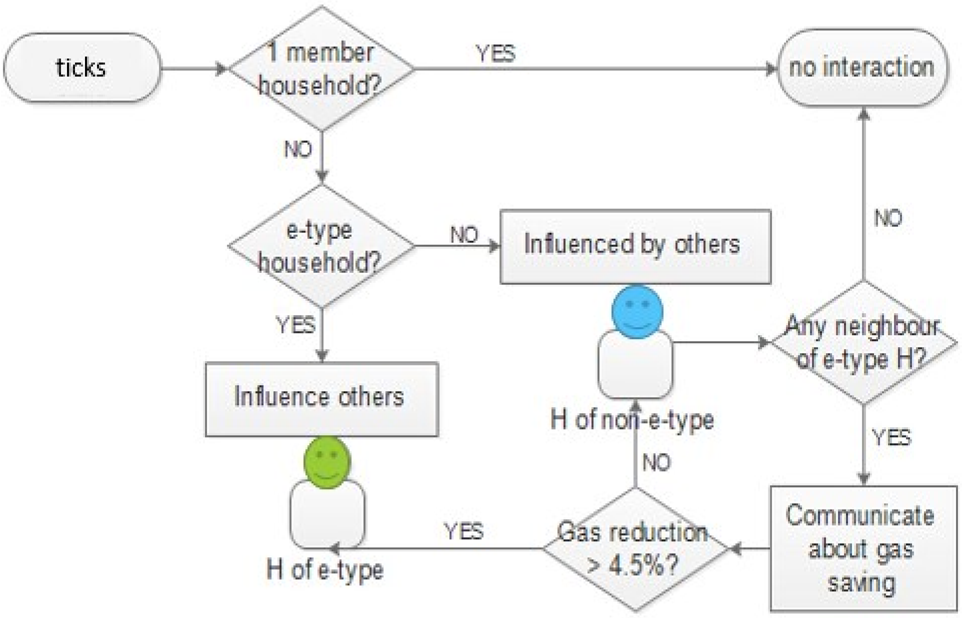


Figure 4-4. Interactive Behavior of household agent

4.4 Simulation of the effect of Environmental Tax Policy

4.4.1 *Simulation Scenarios and Initial parameters*

In this research, 4 scenarios were designed to make the simulation. The first one is the scenario with the Environmental Tax policy interruption as the real case. The second one is the scenario without any policy interruption. The third is the scenario with a stronger “Environmental Tax policy” interruption. The fourth one is the scenario with a stronger interaction among household agents.

Scenario 1: Environmental Tax Policy Scenario: This scenario is most close to the real situation in Kanazawa, it uses the simulation approach to reflect the truth and reals more details than statistic data. It is used for 3 purposes, first one is the verification of the ETS, which is the basic of analysis of all the simulation result. The second purpose of this scenario is to explore the internal relationships between the policy and the household behaviors. The third purpose is to be a control group when analyzing other hypothetical policy scenarios.

Scenario 2: Blank control Scenario: This scenario is a blank control scenario, the Environmental Tax policy is excluded in this scenario, which means the Environmental

Tax in the model is set as 0. Meanwhile, the price change caused by other factors are same as the environmental tax policy scenario. Therefore this scenario could be compared with the environmental tax policy scenario and the comparison result could be an evidence of exploring the effect of the policy.

Scenario 3: Intensive Tax Scenario: This scenario is designed with a more intense Environmental Tax policy in hypothesis. In this scenario, the Environmental Tax is supposed to be added double times as it conducted in real case. The price change of this scenarios are set as it showed in Table 4-7.

Table 4-7. Price change in intensive environmental tax hypothetical policy scenario

	Before 2013.04	**2013.04-2014.04**	**2014.04-2014.10**	**After 2014.10**
Unite gas price(yen)	$P_{original}$	$P_{original} + 0.42$	$P_{original} + 0.84$	$P_{original} + 1.26$

When it is applied in the model, it followed the equation:

$$ET = \begin{cases} 0, & t < 7 \\ 0.42, & 7 \le t < 19 \\ 0.84, & 19 \le t < 25 \\ 1.26, & t \ge 25 \end{cases}$$

The purpose of setting this scenario is to explore the Environmental Tax policy in Kanazawa city further by checking the household behaviors with a stronger interruption of price change.

Scenario 4: Intensive Interaction Scenario: The scenario of intensive households' interaction means the interaction between households are more intense than the real case. The interaction between households represents the communication about gas consuming. The stronger interaction is usually achieved with the propaganda and education about gas saving importance and tips. These kinds of activities are usually carried out in a living community. The purpose of this scenario is to examine the effects of policies on households' behavior by comparing between the policy with price change and the hypothetical policy of promoting the propaganda and education among households. This scenario will be a complementary evidence of exploring the Environmental Tax policy effects on households gas consuming.

The basic parameters such as households' locations, human numbers in each household, and the income of each household are set based on the former researches. The parameters settings of each scenarios are shown in the following table.

Table 4-8. Parameters settings of each scenarios

Scenarios	Price-increase-rate	Interaction-intensity
Environmental Tax Policy Scenario	1	1
Blank control Scenario	0	1
Intensive Tax Scenario	2	1
Intensive Interaction Scenario	1	2

4.4.2 *Model Verification*

The model verification of this research is conducted by comparing the simulation results with statistic data from Kanazawa government. The simulation of the Environmental Tax policy using the parameters matching with the real case in Kanazawa has been conducted for 20 times to eliminate the accidental errors. All of the simulation results are input into the R software. The results are shown in Figure 4-5. This research focus on the results of overall households' gas consumption, when considering the results analyze, the average household gas consumption is used to eliminate the interference of population change. During the 30 months period, the population in Kanazawa city has changed, however, in the simulation model, it is supposed there is no population change. Thus it is more accurate to analyze the average household gas consumption. As the statistical data after December 2013 is not published, thus the statistical data comparison is conducted in the period from October 2012 to December 2013.

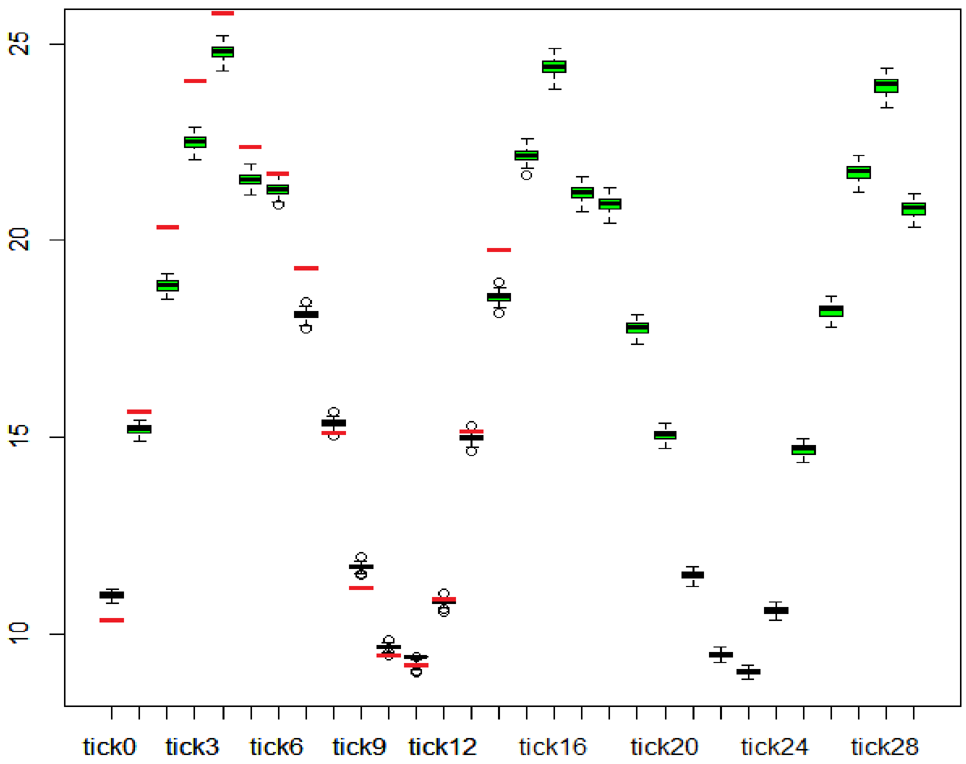


Figure 4-5. Comparison between simulation result and statistical data

From the simulation results, we can see from tick3 to tick8, the data from statistic data are higher than the simulation results. The gas use of heating is not considered in this research. However, statistic data calculated the whole gas use of households, thus when it is seasons with gas use for heating, the simulation results will be smaller. Despite this error, the average gas consumption of statistic data and simulation results are almost at the same level. Therefore, it could be regarded that the ETS reflects the truth well.

4.4.3 *Result and Discussion*

The households' gas consumption is analyzed from three aspects: the analysis of policy effects on average gas consumption, the analysis of average household gas consumption in each income group, the analysis of overall households' gas consumption in each income group.

(1) The policy effects on average gas consumption

The policy effects is analyzed by comparing the simulation results of Environmental Tax Policy Scenario and the Blank Control Scenario, the average household gas consumption is the object.

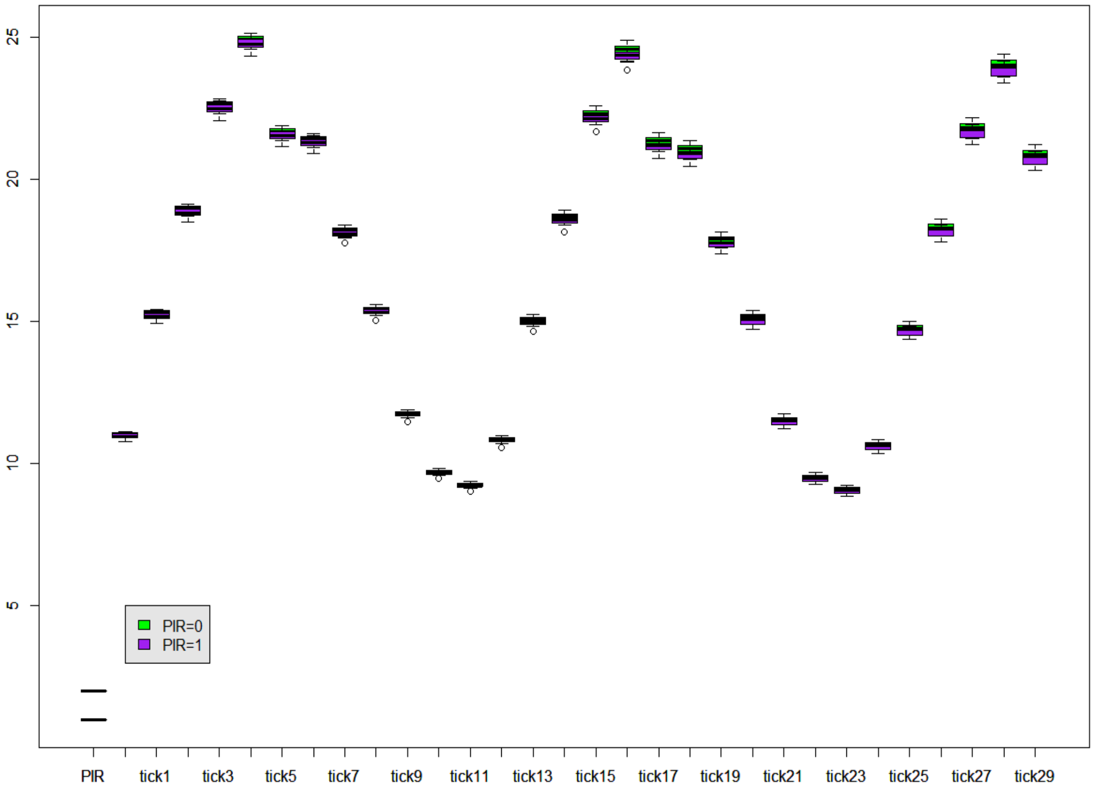


Figure 4-6. The policy effects on household average gas consumption

In figure 4-6, the green part with “PIR=0” means price-increase-rate equals 0, which represents the Blank Control Scenario. The purple part with “PIR=1” represents the Environmental Tax Policy Scenario. From the figure, the results of the two scenarios is almost at the same level. The result of Environmental Tax Policy Scenario is slightly lower than the Blank Control Scenario and in any tick, there is no result that the Blank Control Scenario is lower than the Environmental Tax Policy Scenario. Therefore, it comes to the conclusion that, comparing with the Blank Control Scenario, the average household gas consumption of Environmental Tax Policy Scenario is slightly lower. It could be considered the Environmental Tax policy has some effects on household gas consuming, although the effects is not obvious.

(2) Average gas consumption in each income group

The average gas consumption in each income group is also analyzed with the comparison of Blank Control Scenario, which could be a good evidence of checking the policy effects. The simulation result of average gas consumption in each income group is shown in Figure 4-7. It is obviously that the gas consumption of each income group differ a lot. The difference between low income group and middle income group exists but compared with the high income group, it is much smaller. The difference inside the rich group is also bigger than in other income groups, which means the gas consuming behavior inside the high income group is of great diversity.

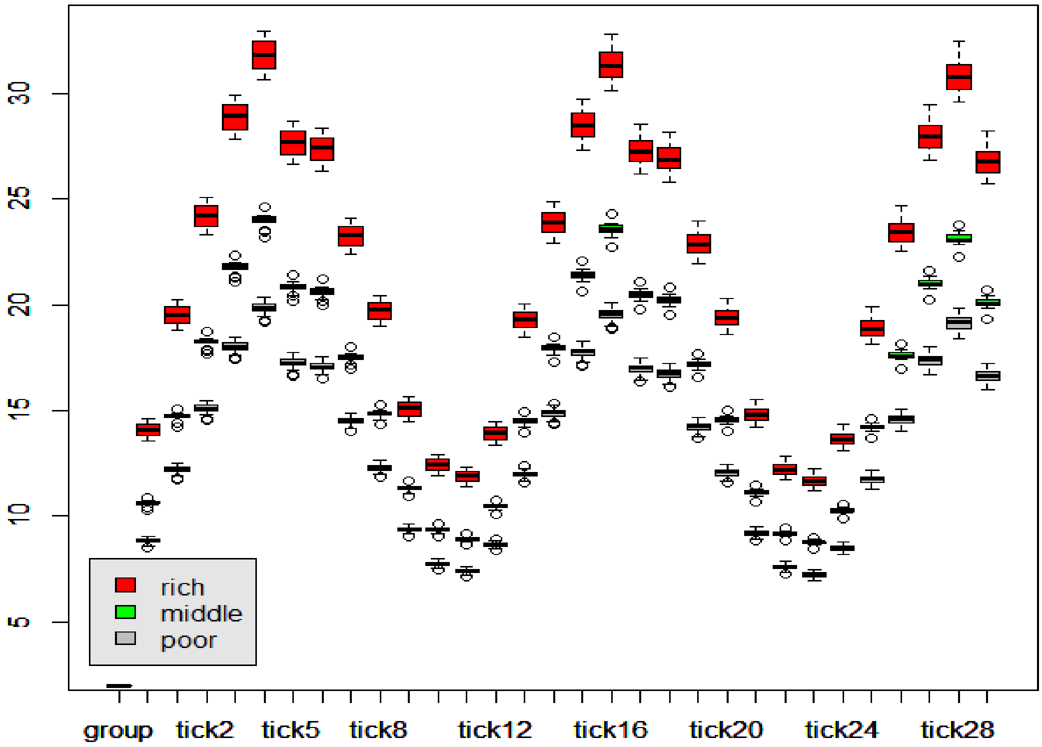


Figure 4-7. Average gas consumption in each income group with Environmental Tax policy

To see the Environmental Tax policy effects on each income groups, the simulation results of households' gas consuming in each income groups with the Environmental Tax Policy Scenario and the Blank Control Scenario is compared as shown in Figure 4-8.

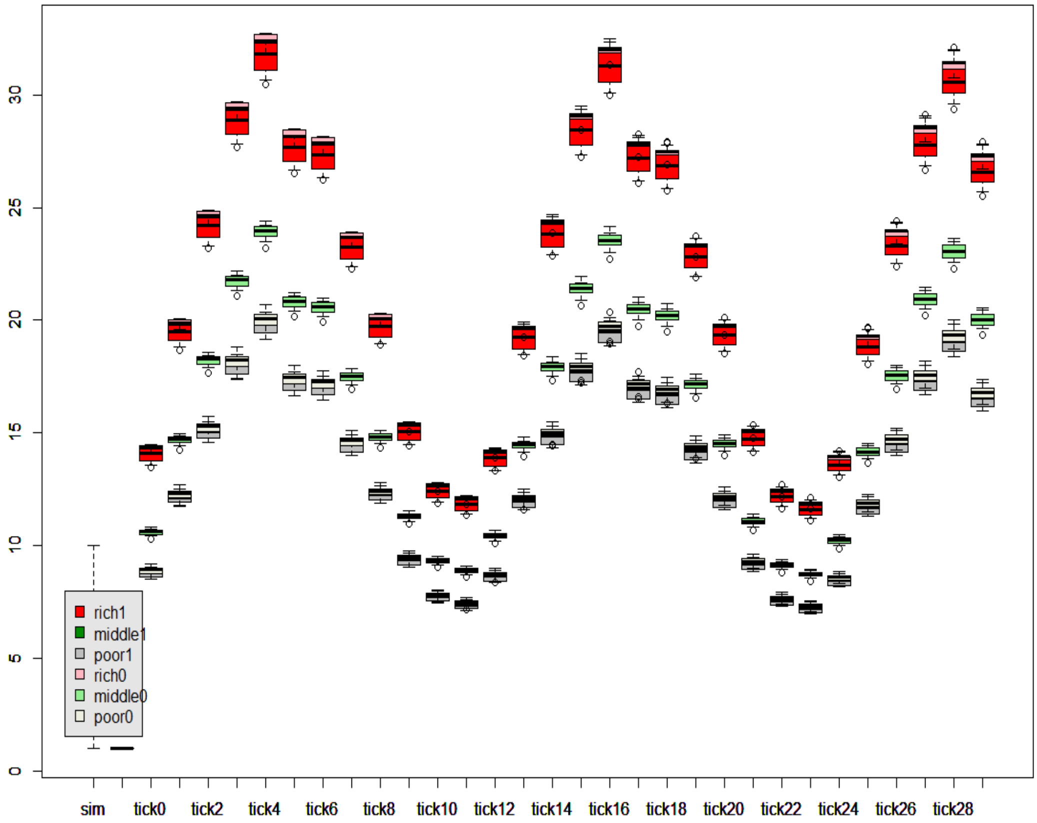


Figure 4-8. The policy effects on average household gas consumption in each income group

Here the figure with darker color are the results with the Environmental Tax Policy Scenario, of which the labels are “rich1”, “middle1” and “poor1”. The figure with lighter color are the results with the Blank Control Scenario, of which the labels are “rich0”, “middle0” and “poor0”.

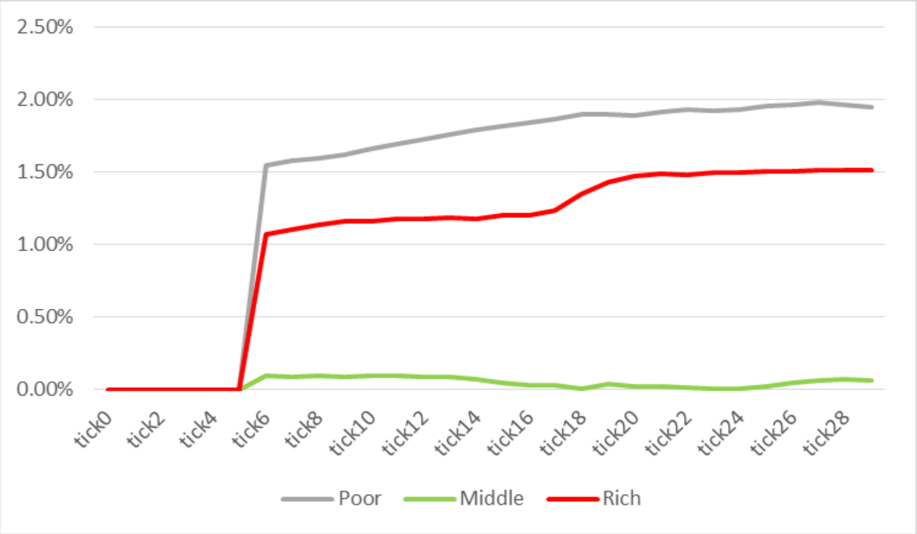


Figure 4-9 Policy effect of scenario 1 for different income

From the figure, we can see that the policy has effects on each income group. However, the effects intensity different a lot in each income group. The group with the most significant policy effects is the group with low income. Almost in every tick of the simulation, meaning every month of the research period, the households with low income reduce their gas consumption. The high income group also reduced their gas consumption in the research period, but the volume of gas saving is less than in the group with low income. There is almost no difference of the results between the Environmental Tax Policy Scenario and the Blank Control Scenario in the group with middle income. Therefore, we comes to the conclusion that the Environmental Tax Policy has the most significant impacts on the households with low income, and has the most insignificant impacts on the households with middle income.

(3) Overall gas consumption in each income group

The overall gas consumption in each income group is analyzed for exploring the features of policy effects on all the households. Firstly, the households' total gas consumption in each group with Environmental Tax policy is analyzed, the results are shown in Figure 4-9.It is obvious that the total gas consumption of households with middle income is the most among all income groups. As the simulation is based on a virtual Kanazawa city with a proportionately smaller scale of Kanazawa city, the proportion of households in each income group is the same as Kanazawa city. The households with middle income take the largest percentage. Thus the results is mostly due to the big population base of middle class households. Therefore, it indicates that the policy targets on households with middle income may play a better effects.

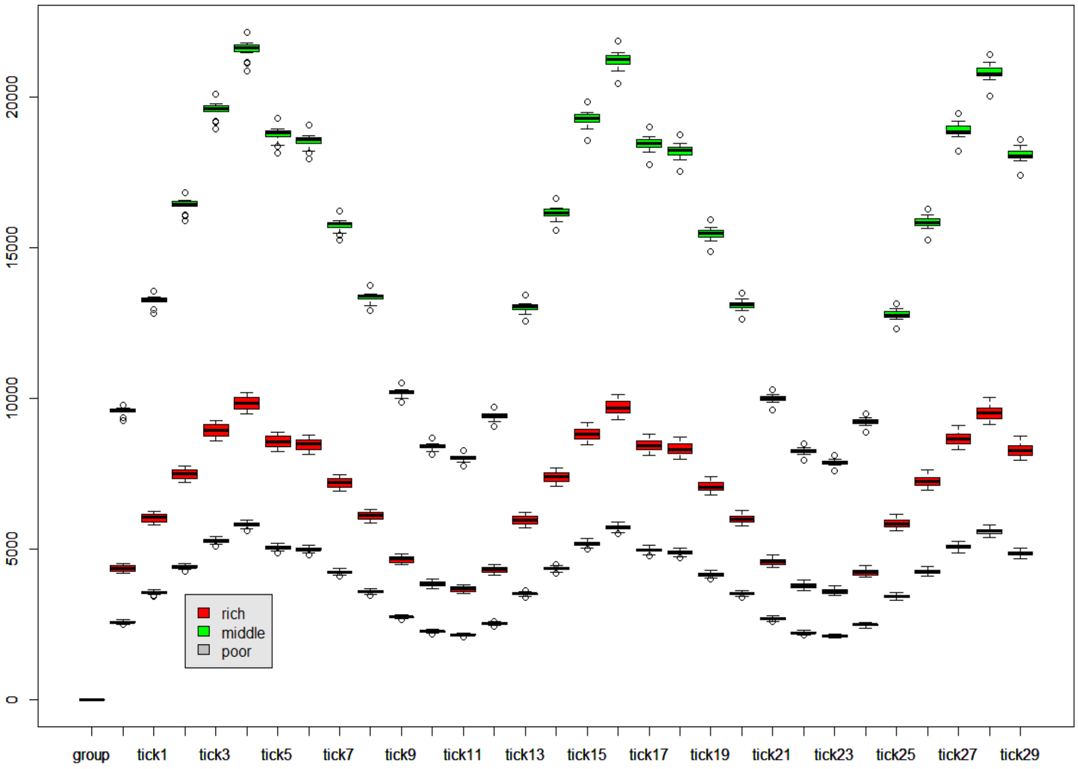


Figure 4-10. The total gas consumption of households in each income group with the policy

Next, the effects of Environmental Tax policy on the overall gas consumption in each income group are explored. The overall gas consumption of households in each income groups are compared with the two scenarios of the Environmental Tax Policy Scenario and the Blank Control Scenario. The results are arranged in Figure 4-10.It indicates that the policy effects of each income group different a lot. For the households with middle income, the gas consumption is almost the same with the two scenarios, there is no signs that the policy has any effects on the middle income group. For the rich households and poor households, there are some gas saving behaviors happened, which can be concluded by the feature shown from the figure that the total gas consumptions are decreased. However, the policy effects is limited because the gas consumption decreasing degree is not significant.

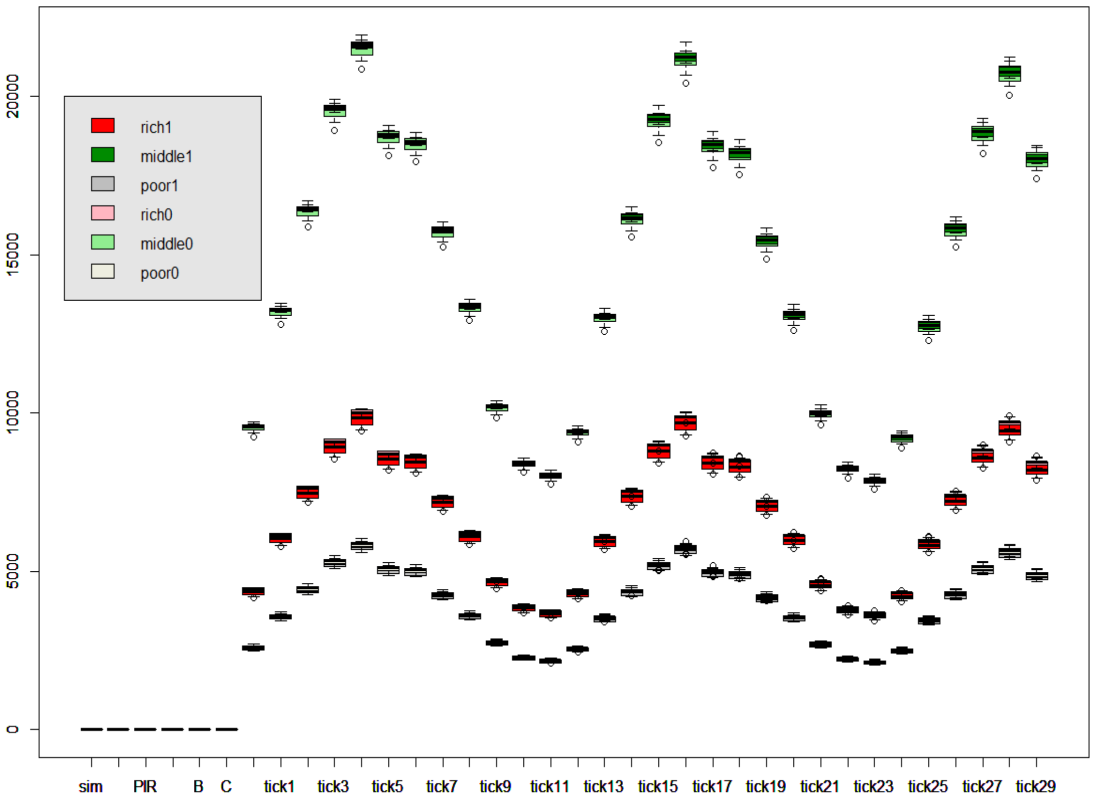


Figure 4-11. The policy effects on overall households' gas consumption in each income group

To understand the households' gas consuming behaviors further, some hypothetical scenarios are simulated in the ETS, the results are analyzed as a comparative study. As the results of Environmental Tax policy effects on households' gas consuming behaviors, the policy impact intensity is not obvious. There may be many reasons for this result, but from the aspect of policy content, the reason that the price change is too small to change the behaviors of the households naturally comes out. Therefore, to see whether the impact of price change is too weak to influence the households' behaviors, a hypothetical policy with double time of the original price change is made and is simulated with the ETS. The results of Intensive Environmental Tax Hypothetical Policy Scenario, Environmental Tax Policy Scenario and the Blank Control Scenario are compared as shown in Figure 4-11.The households' gas consumption result of Intensive Environmental Tax Hypothetical Policy Scenario is lower than that of Environmental Tax Policy Scenario and Blank Control Scenario, which means the more intensive price change has a greater impact on households' gas consuming. However, comparing with the Blank Control Scenario, the results of Intensive Environmental Tax Hypothetical

Policy Scenario changed not so much neither. Therefore, it could be considered that the price change influence the households' gas consuming behaviors, but the impacts of price increasing policies on gas consumption volume is limited.

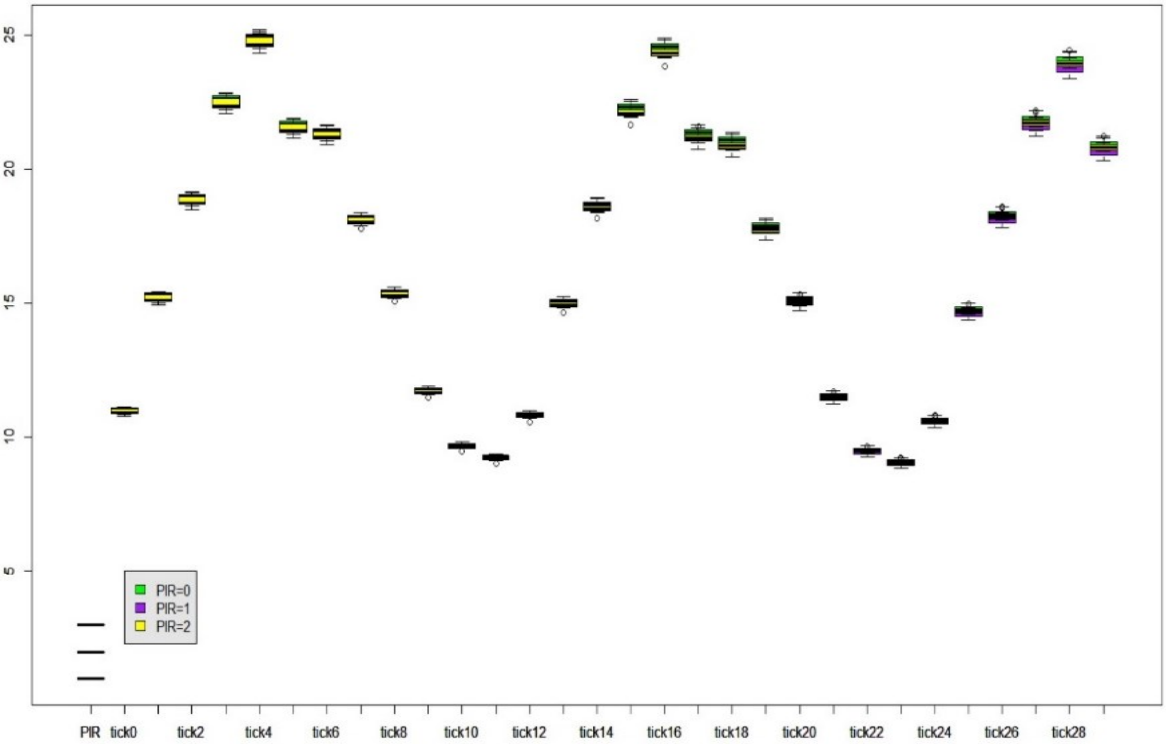


Figure 4-12. Households' gas consumption with different price change

From the result above, we can see that the price changing policies influence the households' gas consumption with a slight impacts. As suggested by other researches, promoting the awareness also help the households energy saving. Therefore, the Intensive Households' Interaction Scenario is analyzed by comparing the results with the Environmental Tax Policy Scenario. As figure 4-13 showed, promoting the interaction intensity between households leads to the decreasing of households' gas consumption. The households' gas consumption decreased more significant than the price change scenario. While promoting the interaction between households also means a wider and wider effects among the communities with the passage of the time. From the results of the last five ticks, we could see an obvious change of households' gas consumption, it could be explained as a result of the expend influence of gas saving behaviors in the city. Therefore, this result shows a long time lasting effects of energy saving, which is also suggested in the study of former researches (Wall R, 2009; Brunner K, 2012).

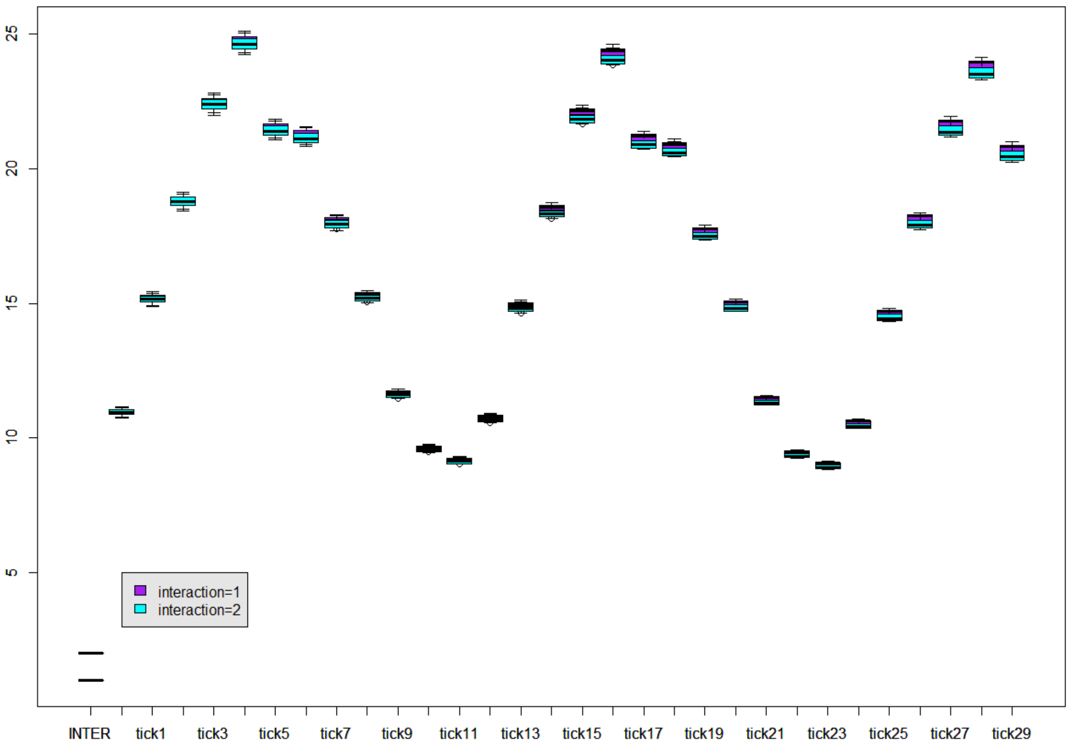


Figure 4-13. Households gas consumption with different interaction intensity

To access the Environmental Tax policy, not only the gas consumption should be analyzed, it is also necessary to analyze the satisfaction of the households. The satisfaction of households is assumed to be in positive correlation with the gas consumption, however there is no seasonal change in the satisfaction of households. Thus the satisfaction level of households different according to the gas consumption, but in each month (each tick in the simulation), there should be no obvious changes like the gas consumption seasonal change. The results of households' satisfaction are shown in Figure 4-14.

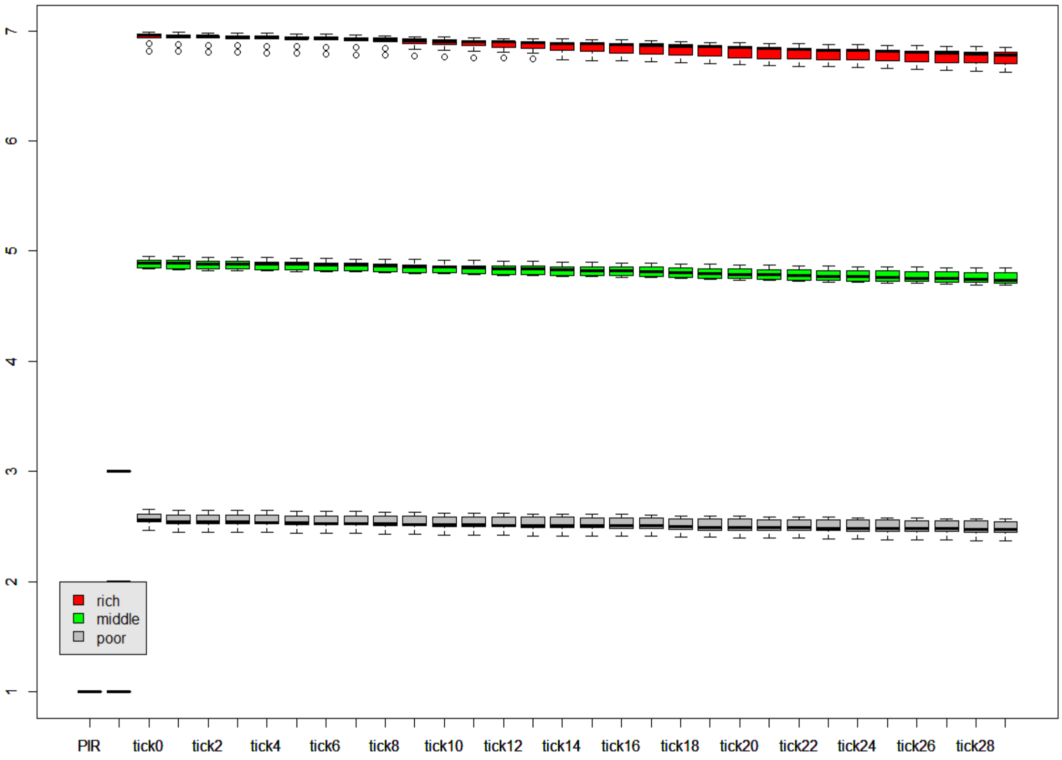


Figure 4-14. Households' satisfaction of each income group with the Environmental Tax policy

There is not much fluctuation in the figures of satisfactions of households in each income group. It is suggested that the energy poverty mostly happens in the households with low income, which means more attention should be paid in the group with low income (Edmond C, 2005). The satisfaction of poor households almost remains at the same level. Therefore it could be considered that no energy poverty happened by the Environmental Tax policy. While there presents a decrease of households with high income group obviously, although the decrease degree is slight. It is supposed that the high income group is more sensitive to the comfort of gas consuming, which means little gas saving will also lead to their decrease of satisfaction.

As the Environmental Tax Policy is made to respond to the global warming countermeasures, it is necessary to analyze the CO_2 emissions with the background of introducing this policy in Kanazawa city. The CO_2 emission is calculated according to the method provided by the Kanazawa water and energy center. The calculation method in this research is shown in the following equation.

$$CO_2\ emission(t-CO_2) = 46.0(Gj/km^3) \times C(km^3) \times 0.0498(t-CO_2/Gj) \qquad eq.\ 4$$

Where, C equals the gas consumption

The equation of calculating CO_2 emission shows a positive correlation between the gas consumption and CO_2 emission, thus the detail analyze of gas consumption could be referred when analyze the CO_2 emission. While with a different scale of the result data, the CO_2 emission analyze is still need to be conducted to some extent. The CO_2 emission results of the Environmental Tax Policy is shown in the following figure. From the simulation results, we could see an obvious decrease of CO_2 emission during the 30 months simulation period. Therefore, it could be considered that the Environmental Tax policy has effects of promoting the CO_2 emission reduction, although the policy effects on households' gas consumption is not so obvious. The reason why it is more obvious with the CO_2 emission could be considered that the scope of the data exaggerates the change caused by the policy. Because the purpose of the policy is on the CO_2 emission, it could be confirmed that the policy has effects on CO_2 emissions.

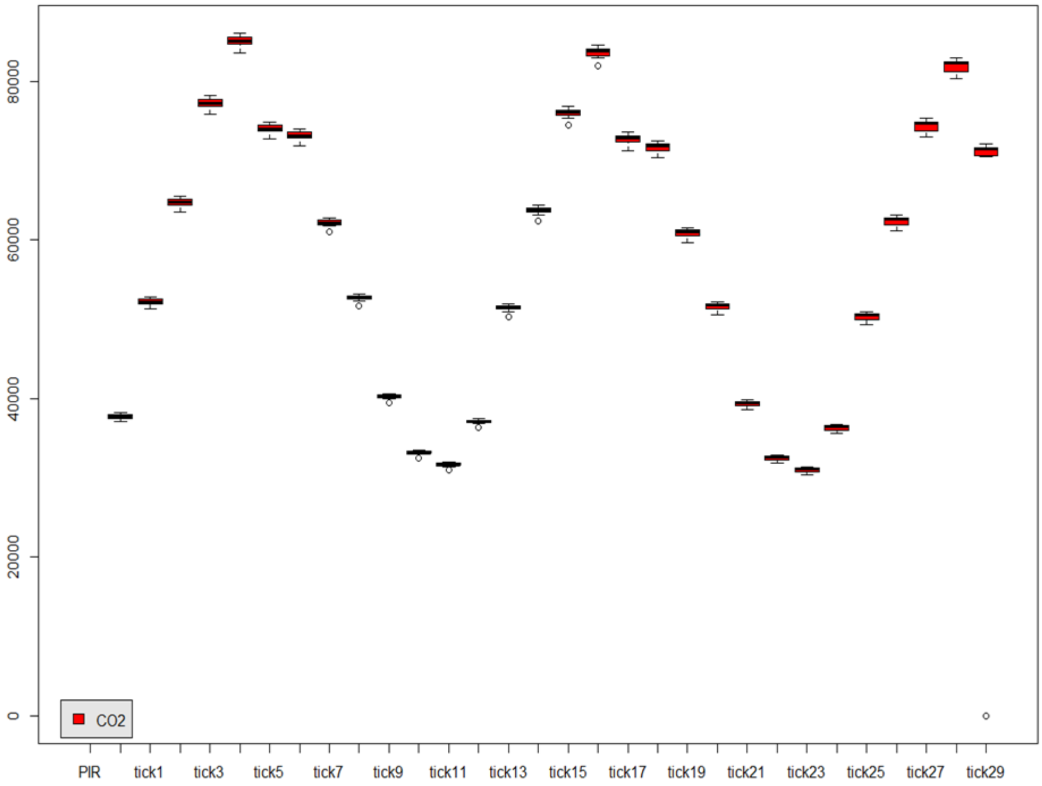


Figure 4-13. The CO_2 emission simulation results with Environmental Tax policy

4.5 Conclusion of this Chapter

For the ETS developed in this research, roughly speaking, it is proved to be capable of simulating the Environmental Tax policy effects on gas consuming behaviors of households in Kanazawa city. With the first 15 months verification, the simulation reflects the real case well. From the simulation results, it shows that the Environmental Tax policy has effects on households' gas consuming behavior and CO2 emission reduction. There is no energy poverty happened because of the policy. However, the gas price changing didn't make the households' behaviors changed a lot, meaning the price changing method works not efficiently enough. With the analysis of different income group, A hypothesis of promoting the interactions between households presents a better result of households' energy saving. Based on the simulation results in this research, with the reference of other researches on energy policy, the price changing didn't cause any energy poverty and there are some effects on CO_2 emission reduction, thus the policy is thought to be feasible to be continued. However, it is suggested to pay more attention to propaganda of energy saving, which could promote more households conduct the method of energy saving. In this research the propaganda is simulated with a more intensive interactions between households, while in real case it could be conducted by organizing more activities on energy saving in communities.

At the present stage, some simulation results of energy policy effects on household behaviors has been obtained in this research. However, there still are some defects need to be resolved, some points could be improved. Firstly, although it has been verified of the first 15 months in the simulation process, the whole process with 30 months still need to be verified with the statistical data after the data becomes available in recent one or two years. Secondly, the household behavior in this research is designed referring the researches results of other researches. Although it is workable to some extent, it will be better if the behavior is designed according to the real case in Kanazawa city, for example obtaining the behavior features with a questionnaire survey. What's more, the energy policy contains more than price changing and propaganda, to make the model serve more purpose, more scenarios should be able to be conducted in the model, which means a more detail simulation process could be developed with more changeable parameters like the price-increase-rate and interaction-intensity in the current system.

Chapter 5 Conclusion

In this PhD research we used agent-based approaches for developing simulation systems. These systems are proved to be useful for planning support of environmental policy for GHG emission management. The policies mainly focus on the industrial sector and residential sector in urban area. The policy for industrial sectors can be divided into total amount control and release standard. While as to residential sector, the environmental policy mainly focus on the residential consumption of GHG related energy which include electricity and gas. Thus, as a research for planning support of environmental policy for GHG emissions, we took three policies as our targets. Respectively, they are GHG total amount control and release standard policy in a rubber city project, a residential electricity sharing policy and an environmental tax policy on residential gas consumption. Regarding to these three policies we developed different systems and simulated the policy impacts by designing the agents' behavior and interactions. As results, the corresponding change in GHG emissions value under the policy impact can be easily forecasted and hereafter, referred by policy decision makers.

In chapter 2, we developed a RCS system based on ABS approach on a Netlogo platform. It is able to describe the developing process of an agro-industrial city resulted by implementation of the rubber city project. The simulation results reflect the effectiveness of total GHG amount control and release standard policy for reducing GHG emissions. The system successfully simulate the policies impact by designing the decision making process related with GHG emission in agents' individual behavior. In this way, the policies proposed in rubber city project have been combined into the simulation for predicting the possible GHG emissions amount during rubber city development and supporting local government decision-making on environmental policy in Nathawi district.

However, in RCS the interaction of agents didn't affect the simulation of environmental policy impact. While environmental policy for residential sector may come together with new technology and create new kind of interactive behavior between households that directly affect residential energy consumption and GHG emissions. Therefore in Chapter 3, we tried to forecast the effect of an electricity sharing policy on improving the using efficiency of PV generated electricity in smart community. In this part, we firstly simulate the electricity consumption of household with four different life routine patterns by an ABS system developed on AnyLogic platform. Then, we developed an ESS system in the Netlogo platform and input the consumption curve as the electricity consumption behavior of household agent. Meanwhile, we also designed the PV electricity generation behavior with several assumptions for household agent. After that, Electricity sharing is set to be an interactions between household agents, while the process is taken charged by control center agent. The rule of electricity sharing in the system is designed completely based on the description of electricity sharing policy. The system can simulate a detailed process of electricity sharing under the initial parameters set according to real situation of Japanese smart community. The simulation thus can be a guidance and support for policy decision-making on community energy management and GHG emissions reduction.

What’s more, gas use is another important perspective of residential GHG related energy consumption. Thus at last, we developed an ETS system for simulating the impact of an environmental tax policy on residential gas consumption and CO_2 emission. The policy in ETS is designed according to an environmental tax policy in Kanazawa in Japan that aims to reduce the residential gas consumption. The system combined individual gas consumption behavior with interactive behavior between households that may affect gas use to simulate the impact of the policy. Hereby, it is able to mimic the reaction of households to the gas price change resulted from the environmental tax policy. Furthermore, comparing with traditional residential energy consumption models, ETS can simulate policy effects through scenario analysis. Thus, the ETS system is possible for planning support of such kind of policies.

However, in this stage the system for planning support of environmental policy that we introduced in this PhD research are all separately developed, together with corresponding policy simulation are separately conducted too. For future work, these systems should be combined into one platform, which can thereby simulate the impact of environmental policy of both industrial sector and residential sector on local GHG emissions during urban development or operation. As a further step, the combined simulation system should also be able to reflect the impact of GHG emissions on agent’s behavior so that the restriction of GHG on urban development could be simulated.

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