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Research article

Agent-Based Simulation of the Effects of an Environmental Tax Policy on Residential Gas Use and CO2 Emissions:Kanazawa city

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Abstract

Environmental tax policy is one of the most important government measures for carbon reduction. In this paper, we implement an agent-based simulation approach to simulate the volume of household gas consumption affected by the Japanese "Tax for Global Warming" which is a typical environmental tax policy on gas price. A self-adjustment module is designed to simulate the process of household gas use behavior change according to the gas price that result in change in value of gas consumption. Furthermore, the CO_2 emissions reduction is calculated based on the change of gas consumption value. Finally, we discuss based on the simulation results concerns about the effectiveness of "Tax for Global Warming" policy on residential gas use and CO_2 emissions by adjusting gas price to affect households' behavior.

Keywords: Agent-Based Simulation, Environmental Tax Policy, CO_2 Emissions

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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 [1]. 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 as table 1 showed: 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.

Table 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/m^3)	$P_{original}$	$P_{original}$ + 0.21	$P_{original}$ + 0.42	$P_{original}$ + 0.63

The objective of this research is to develop an agent-based model with heterogamous gas consuming behaviors to access the Environmental Tax Policy in Kanazawa city.As an agent-based model, it will pay more attention to the household energy consuming behaviors comparing with other researches. In addition, to make the model closer to the real case, the interaction between agents is also a key point, which is rarely seen in the field of energy policy effects simulation. The Environmental Tax policy in Kanazawa city is conducted in recent 3 years, thus the research results could provide some suggestions for the energy policy timely.

2. LITERATURE REVIEW

When it comes to the research of energy 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 [2]. 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 [3]. 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 [4]. 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 [5]. 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 [6]. However, with an overview of the researches based on energy policy model, little attention has been paid to model the impacts on households' behavior[7].

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 [8]. Jordan R et al created an agent-based model of residential mobility and simulated the impacts of a specific urban regeneration intervention [9].

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 [10].

3. SYSTEM FRAMEWORK AND MODEL DESIGN

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 are shown in Figure 1, which could explain the system framework intuitively.

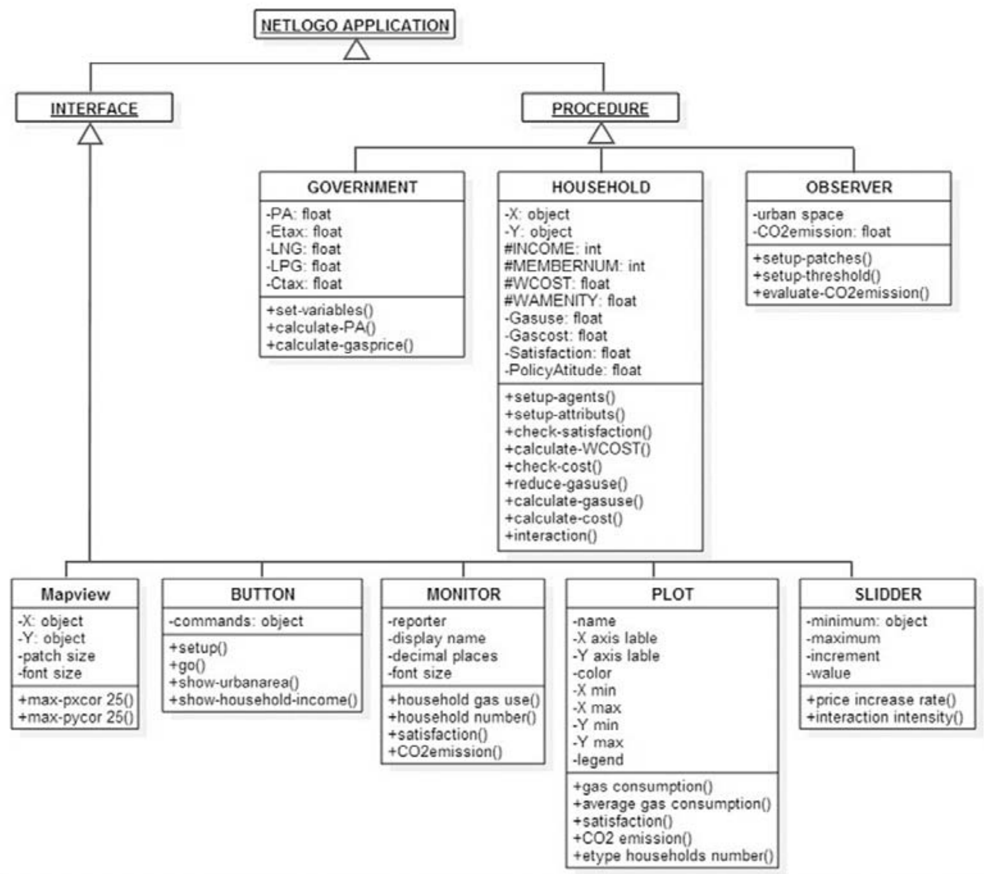

Figure 1. UML class of HGCM

3.1 Structure of the model

For agent based model, it mainly includes three elements: a set of agents, a set of agents' interaction, and the agents' environment [11].In HGCM, there are two kinds of agents: 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 HGCM. The household agent is divided into three groups by income, different income group will have different behavior of gas consuming. There are 1500 household agents in all in HGCM.Each agent in the model has his own attribute and the type of the attribute of each kinds of agents are shown in Table 2.

Table 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 HGCM, 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 CO_2 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 HGCM, 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 in HGCM 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 environment of the HGCM is an urban space of virtual Kanazawa City. It has the basic characters of Kanazawa City. All the household agents in the HGCM are located in the urban space according to the real case[8]. In the virtual Kanazawa City, there are three 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 2.

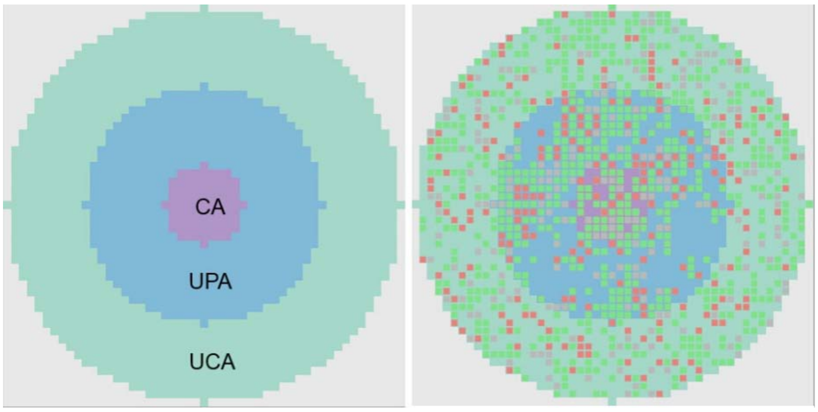

Figure 2. The urban land zone and household locations of the virtual city

3.2 Government behavior

The government behavior in HGCM includes two parts. Firstly, the government set the gas price system in Kanazawa city, which will be the foundation of the policy. Secondly, the government agent will conduct the environmental tax policy as the Kanazawa water and energy center introduced.

Kanazawa water and energy center implements the tiered gas pricing system. The gas charge of one household is calculated as the following equation:

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

Where,

GC: Gas Charge

BP: Base Price

BUP: Base Unit Price

PA: Price Adjustment

ET: Environmental Tax

C: Gas Consumption

CT: Consumption Tax

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 presented in Table 3.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. It is considered in the design of government behavior.

Table 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 the environmental tax of gas consuming as shown in the introduction. 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. Thus, in the simulation, the policy is implemented totally according to the real case.

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

Where,

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

3.3 Households behavior

The households' behavior is designed according to the literatures about households' energy consuming behavior. Because of limited data, there also some assumptions have been made. Based on these two points, the household's decision-making process has been developed.

3.3.1 Households' energy consuming behavior

For designing the agent behavior, there needs some evidence to support the design. In former researches mentioned in literature review on agent-based simulation, the evidence may be the survey results or some theoretical conclusions that has already confirmed such as some mathematical model. In this research, because of limited research condition, surveys like questionnaire survey hasn't been conducted. 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 HGCM.

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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.

Table 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]
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 [12].

For households' energy consuming, it has shown financial resources (income) to be a major determinant for energy use [13]. Households with high income use more energy to achieve a more resourceful lifestyle. Low income households tends to use less "unnecessary energy", which means

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 [14]. 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 [2].

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 the HGCM [15].

3.3.2 Assumptions of household behavior

The assumptions of household behavior mainly include 6 parts:

(1) The assumption of policy affect households: there are many kinds of policies related to energy saving, which may belong to the methods listed in Table 4. But only Environmental Tax policy is considered, so it is assumed that other policies don't have effects on households.

(2) The assumption of behaviors related to energy price: 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. However, in this research it is assumed that income is the most important factors as the literature showed above, and other factors including the member, the location also have some effects.

(3) The assumption of saving energy behavior: 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 5.

Table 5. Gas Saving Behavior Assumptions [15]

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 6.

Table 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) The assumption of gas use of households with different income group: Because there is not enough data of Kanazawa city, it is referred to the data of Tokyo. Then adjustment has been made to make it close to the situation in Kanazawa. The results of survey in research by Schaffrin is also referred in the HGCM[2].

(5) The assumption of relationship between gas use and satisfaction: 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 based on the research results mentioned above.

(6) The assumption of gas use purpose: 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.

3.3.3 Household Decision-making process

Each household agent has to make decisions about their gas consuming, the decision-making process mainly has two parts: the process of deciding the gas consuming based on their own gas consuming situation and the process of interactions with other household agent.

In HGCM, each household will decide their gas consuming behavior as shown in Figure 3 and Figure 4. The decision-making process will be conducted in every tick of the simulation, which means every month the household agent will do the decision-making process.

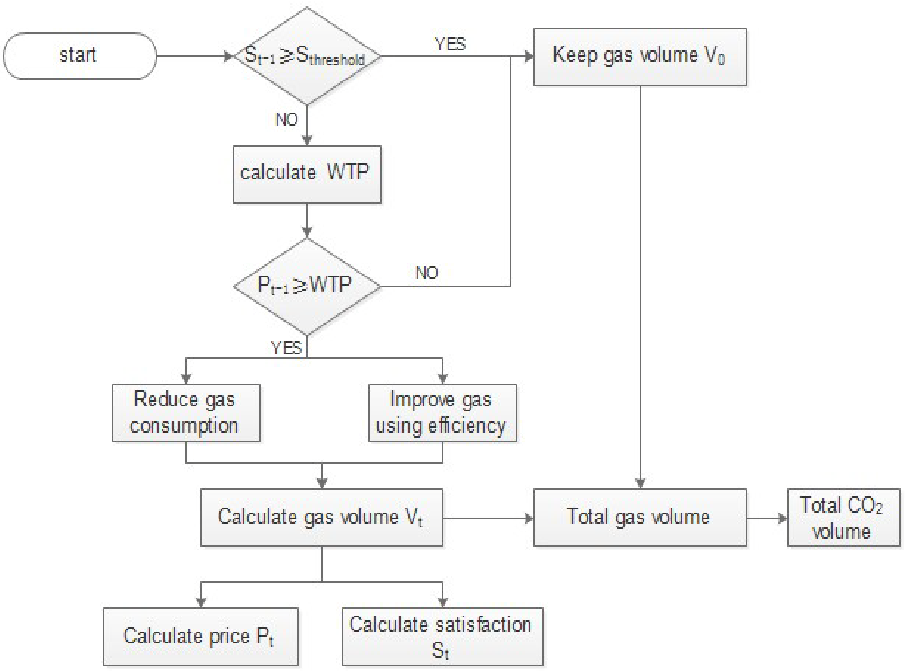

Figure 3. Decision-making Process of Gas Consumption within the Household

In Figure 3, we could see how a household makes his decision. When the decision-making process starts, the household will check his satisfaction first, if the gas consumption is under the basic satisfaction threshold, he will just keep the gas consumption of the basic consumption. If not, he will check the cost for the gas, if the cost is less than the money he wants to pay, he will just keep the gas consumption without any change. If else, the household will want 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, the way the household chooses is based on the income [16][17][18][19]. The poor household is more likely to choose to reduce the overall gas consumption, while the rich household will mostly 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.

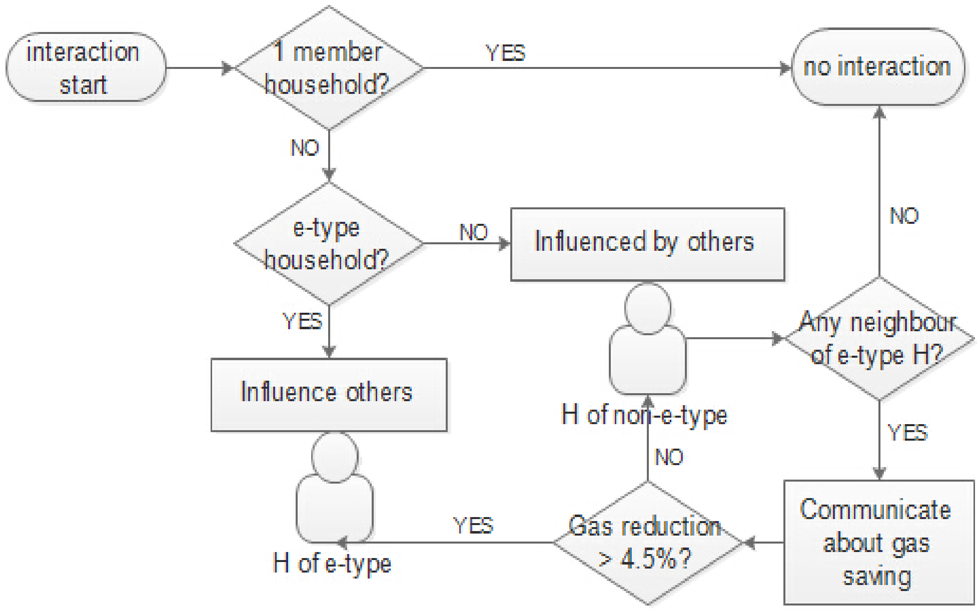

Figure 4. Decision-making Process of Households Interaction

Figure 4 shows the process of decision-making process of households' interaction. When the process starts, it will first choose the objective households, which means the households will have interactions. In this model, it is considered that households with more than 1 member is more likely to be a family. The family households are more likely to have the interactions. Thus if the household contains only 1 member, there will not be any interactions. For the family households, it will divide the households 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 household is thought knowing the tips for saving gas. These e-type households will influence the others by communicating with their neighbors. After the interaction, the non-e-type household may reduce their gas consumption, but also may not take the suggestions from their neighbor. Thus there is a decision-making of assessment for the e-type household. The households influenced by others, if they reduced their gas use more than 4.5%, will turn into the type of e-type household.

4. SCENARIO DESIGN

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 HGCM, 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 Environmental Tax Hypothetical Policy 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 7.

Table 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 3

$$ET = \begin{cases} 0\,, & t < 7 \\ 0.42, & 7 \le t < 19 \\ 0.84, & 19 \le t < 25 \\ 1.26, & t \ge 25 \end{cases} \qquad eq.3$$

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 Households' 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 [8].The parameters settings of each scenarios are shown in the following table.

Table 8. Parameters settings of each scenarios

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

5. SIMULATION RESULTS AND DISCUSSION

5.1 Model Verification

The model verification of this research is conducted by comparing the simulation results with statistic data of 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, the results are shown in Figure 5. This research focus on the results of overall households' gas consumption, 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 consumedthat there is no population change. Thus it is more accurate to analyze the average household gas consumption. Because the statistical data after December 2013 is not published, the statistical data comparison is conducted in the period from October 2012 to December 2013.

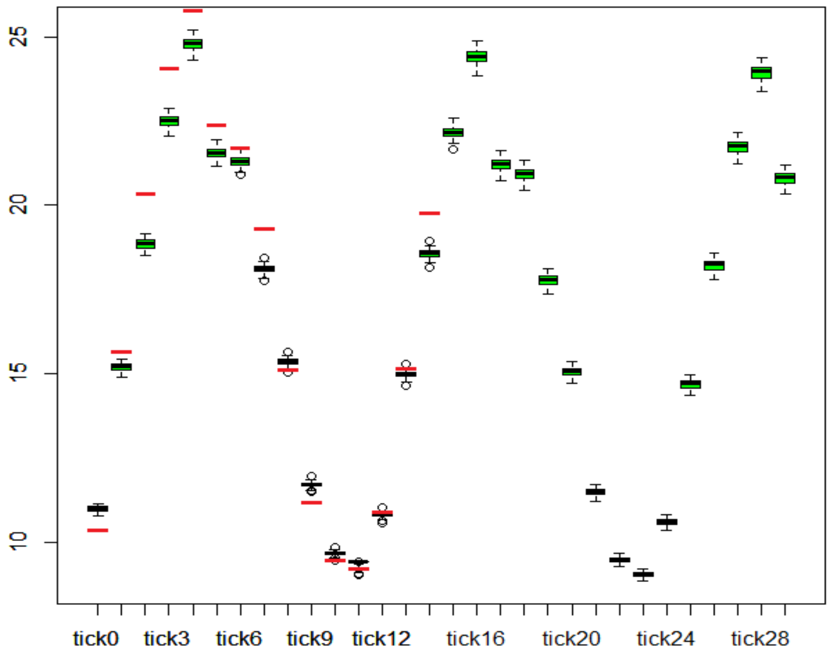

Figure 5. Simulation results and statistic data of average household gas consumption

From tick3 to tick8, the statistical data is higher than the simulation results. The gas use of heating is not considered in the simulation while the statistical data included the whole gas use of households.As a result,in the seasons that gas is used for heating, the value of simulation results will be smaller than statistic data.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 HGCM could reflect the real situation well.

5.2 Households gas consumption

5.2.1 Households gas consumption analysis

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.

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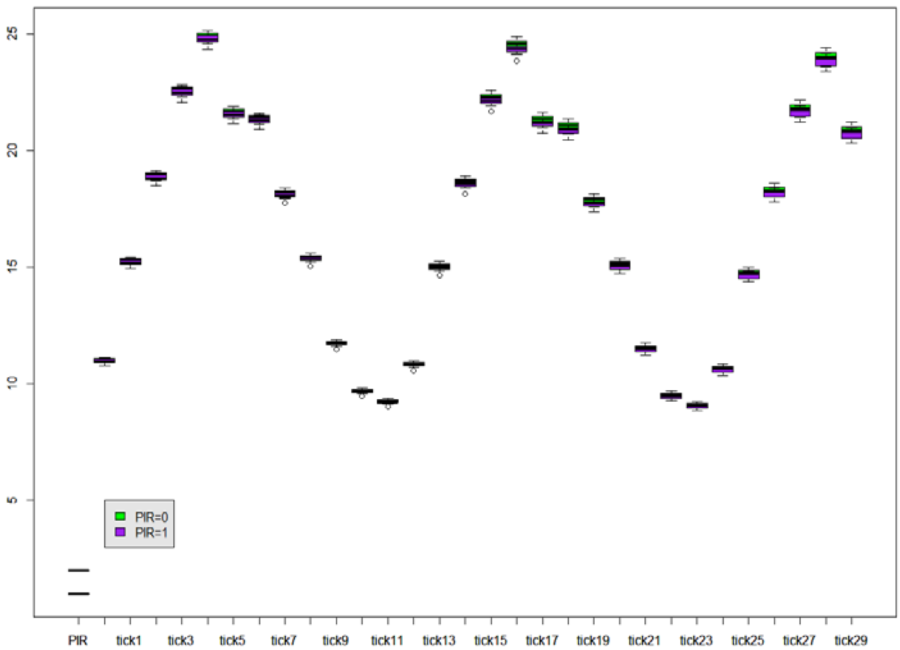

Figure 6. The policy effects on household average gas consumption

In figure 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 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.

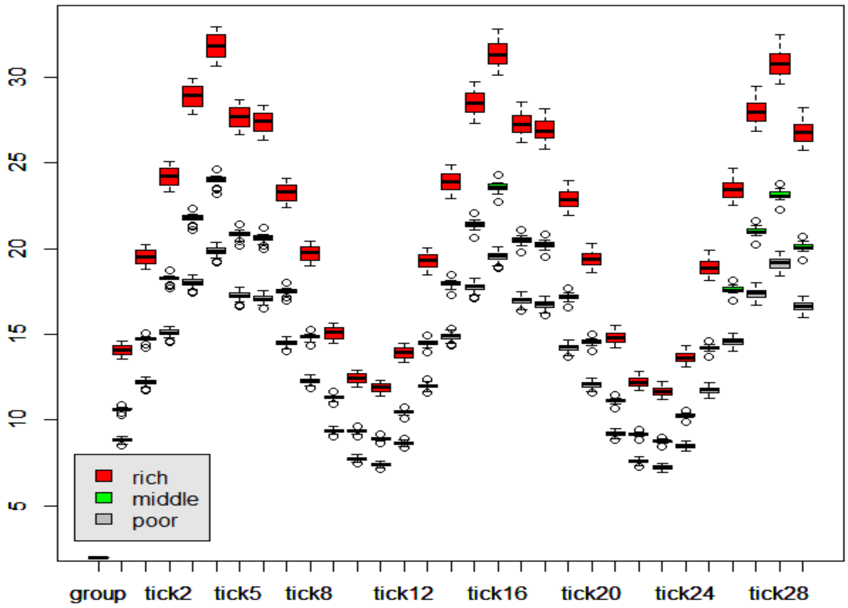

Figure 7. Average gas consumption in each income group with Environmental Tax policy

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 8.

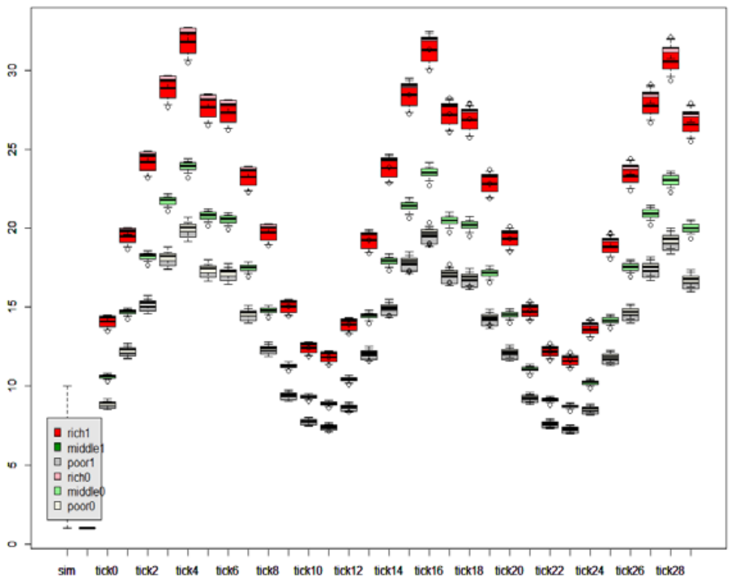

Figure 8. The policy effects on average household gas consumption in each income group

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".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 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.

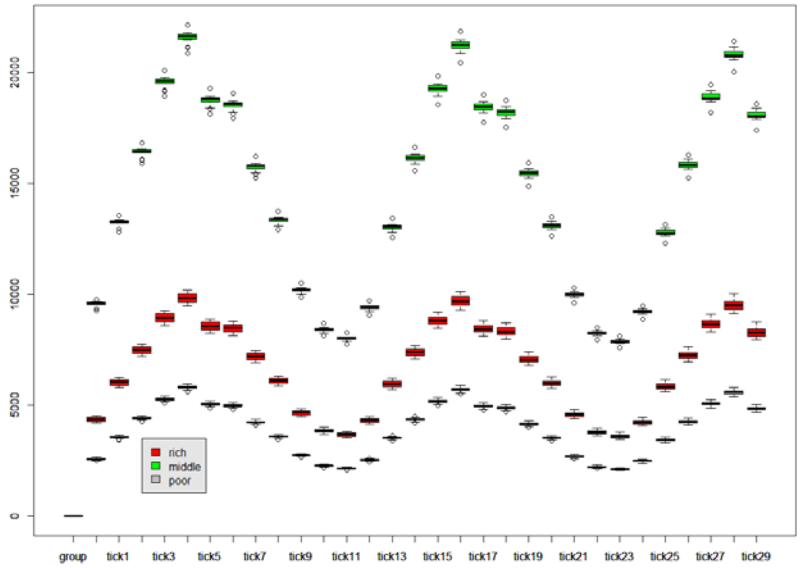

Figure 9. The total gas consumption of households in each income group with the policy

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 10.It indicates that the policy effects of each income group different a lot. For the households with

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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.

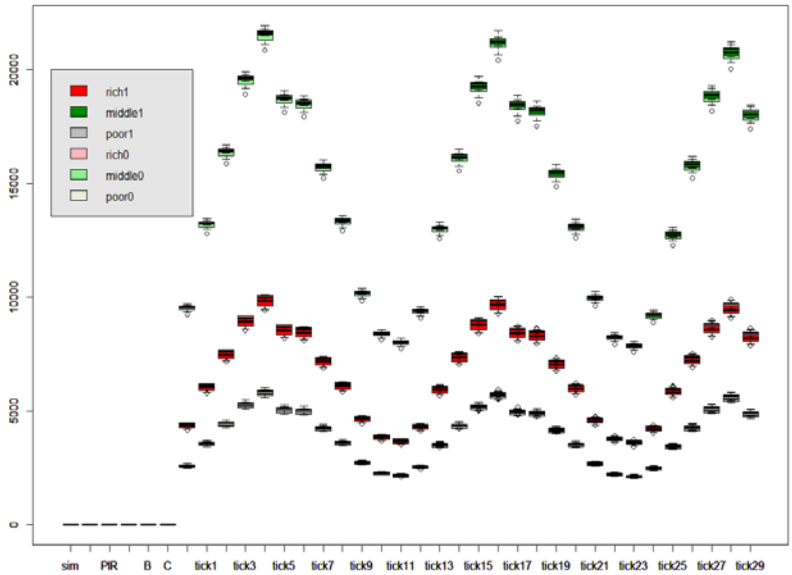

Figure 10. The policy effects on overall households' gas consumption in each income group

To understand the households' gas consuming behaviors further, some hypothetical scenarios are simulated in the HGCM, 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 HGCM. The results of Intensive Environmental Tax Hypothetical Policy Scenario, Environmental Tax Policy Scenario and the Blank Control Scenario are compared as shown in Figure 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.

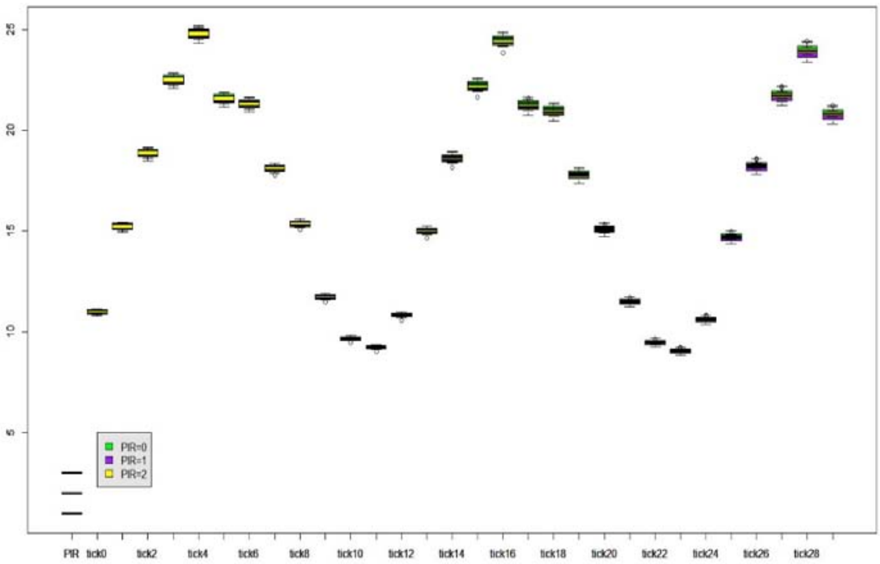

Figure 11. Households' gas consumption with different price change

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 12 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 [20][21].

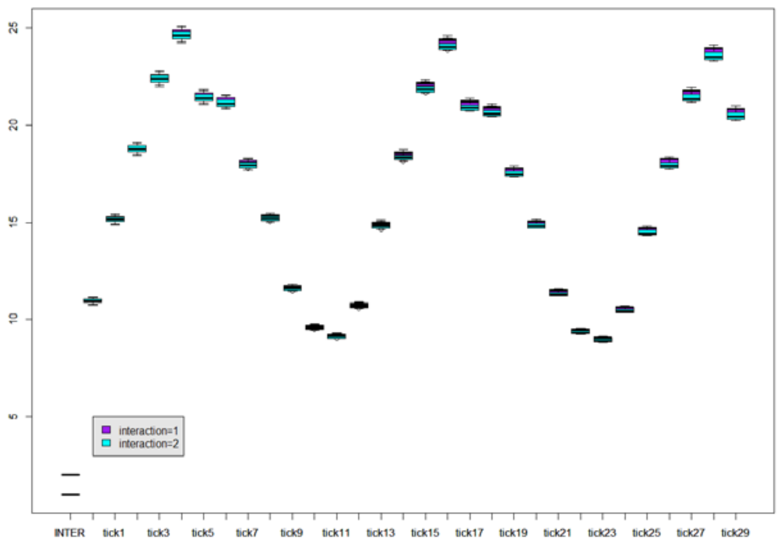

Figure 12. Households gas consumption with different interaction intensity

5.2.2 Households satisfaction analysis

The satisfaction of households are analyzed for checking whether energy poverty has happened. 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 13.

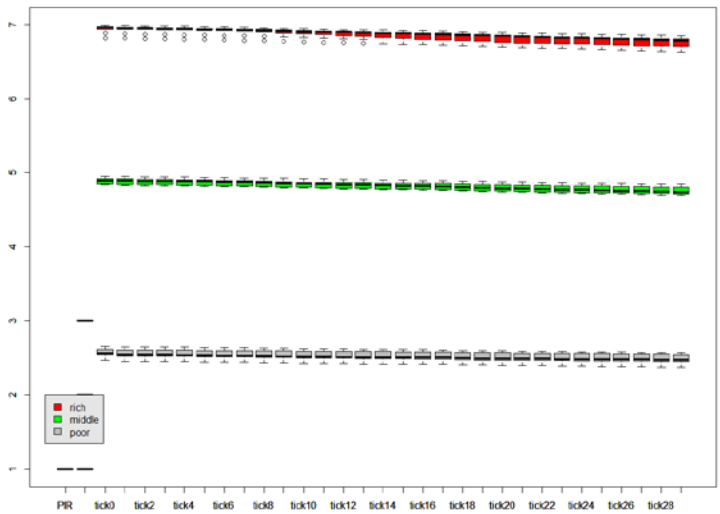

Figure 13. Households' satisfaction of each income group with the Environmental Tax policy

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 [14]. 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.

5.2.3 CO_2 emissions

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.

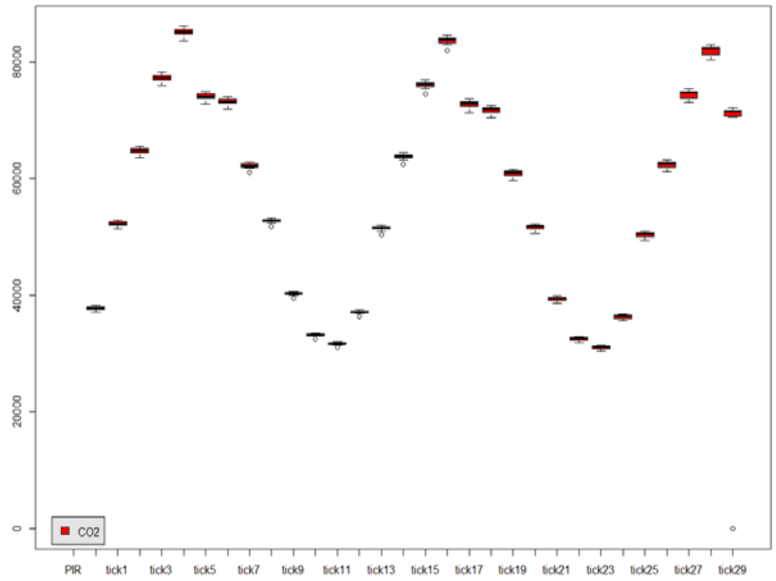

Figure 14. The CO_2 emission simulation results with Environmental Tax policy

6. CONCLUSION AND FUTURE WORKS

The conclusions of this research are organized from three aspects: the assessment of the HGCM, assessment of the Environmental Tax policy in Kanazawa city and the suggestions for the policy makers.For the HGCM 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 CO_2 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 CO2 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.

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