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URBAN-RURAL ENERGY INEQUITY IN KOREA AND POLICY SOLUTIONS

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Abstract

Korea has faced disparities in access to natural gas between urban and rural areas. For example, rural households bear more burden than urban households when it comes to use of energy for cooking and heating. The main reason for this inequity in energy provision is attributed to the imbalanced penetration rate of natural gas. Rural households should depend more on relatively expensive liquefied petroleum gas (LPG) in a cylinder and kerosene for cooking and heating, whereas urban households almost totally depend on cheap natural gas.

To alleviate this energy inequity, Korean government has implemented a new project, which entails installation of LPG storage tank and pipelines in small villages. In this regard, rural households can use LPG more easily, safely, and efficiently. Based on the E4 (energy, environment, economy and equity) framework developed by Young-Doo Wang (2010), the project can be generally evaluated positively. However, the project has some drawbacks with regard to addressing fossil fuels use-in in the long-term. Also, another problem is the lack of a direct subsidy program for rural households.

For a long-term solution, this paper recommends a combination of renewable energy, distributed generation and targeted subsidy programs for rural households. This paper concludes that the current energy voucher program should incorporate residential district applicants as a condition for selecting a beneficiary. In the long-term, the paper also recommends installation of solar PV or residential wind power generation for rural households to reduce energy expenditures.

1. Introduction

Income inequality remains one of the most pressing challenges for economies globally. Adverse impacts of income inequality include widening gaps in environmental, health and educational opportunities in countries, especially emerging economies. It also leads to social conflicts among communities. This kind of inequality also exists in energy sectors, notably in access to affordability of energy services. For instance, Jacobson et al. (2005) analyzed inequality in energy usage between developing and developed countries and concluded that inequality results from income distribution, imbalanced infrastructure network and energy value-chain, and disparate patterns of population distribution in rural areas. Rosas-Flores et al. (2010) studied energy inequality in Mexico and noted that this inequality is caused by differences in consumption of energy types between the higher income and lower income population.

This paper focuses on unequal access to natural gas in Korea which results from imbalanced development of energy infrastructure in the country. The paper evaluates inequality of energy expenditures between urban and rural households, especially the lack of access to affordable heating-related energy services. Equity refers to fairness whereas equality compares two things to each other, therefore, energy equity measures accessibility and affordability of energy supply within a given region or population (Mirnezami, 2014: 36). Consequently, this paper focuses on as energy inequity, not energy inequality.

Chapter 2 shows inequality of energy expenditures between urban and rural areas, and tries to establish the causes of this inequality. The inequality is analyzed by using household survey data conducted by Korea National Statistics Office. Literature review was conducted to establish the extent of energy inequity, particularly access to natural gas supply and relative prices of fuels. This paper summarizes the extent of inequality in a table showing that most households that consume natural gas are situated in urban areas. A graphical analysis is also provided showing the relationship among LNG penetration rates, proportion of agricultural, fishery and forestry households. In chapter 3, analysis of LPG storage facility is introduced; this is an ongoing government policy to mitigate inequity in the energy sector. This LPG storage facility project is evaluated based on an E4 framework (see Wang, 2010). Finally, chapter 4 recommends new policy options to mitigate the energy inequity between urban and rural households. The paper recommends creation of subsidy policy instrument as well as investment in renewable energy and distributed generation systems to address inequitable distribution of energy infrastructure in the country.

2. Energy Inequality in Korea

2.1. Data

Energy expenditure data by income levels and regions for both rural and urban areas comes from household surveys conducted by Korea National Statistics Office (KNSO). This paper uses the household survey data from 2014 to 2016. The data includes household sizes, income, energy expenditures for each energy type, and location of the household (whether rural and urban) i.e.

Population: all common households living in Dongs, Eups, and Myeons of Korea

- Grouped households like dormitories, accommodations and troops are excluded from the population.
- Households running restaurants and lodges, etc., are excluded.

Sampling

- Size: about 8,700 households
- Sampling: sampling with probability proportional size
- Sampling rate: 0.06%
- Error: coefficient of variation of 2~4% for “expenditure”

Survey period: monthly

Figure 1. A household survey
* Source: Korea National Statistics Office

In the data, rural and urban areas are classified according to the Local Autonomy Act. According to article 2 in Local Autonomy Act, local governments in Korea are classified into the following five major categories: (i) one Special Metropolitan City, (ii) six Metropolitan Cities, (iii) one Metropolitan Autonomous City, (iv) eight Dos, and (v) one Special Self-Governing Province. There are Si, Gun, and Gu under the above categories. And, under Si, Gun, and Gu, there are Eup, Myeon, and Dong. Dong is an area with urban form, while Eup and Myeon are not. In the data, all Eups, Myeons and Dongs are in the Special Metropolitan City and the metropolitan cities are classified as urban areas. As shown in Figure2, Eups and Myeons in Metropolitan Autonomous City, Do, and a Special Self-Governing Province fall under the rural areas category, while Dongs belongs to urban areas.

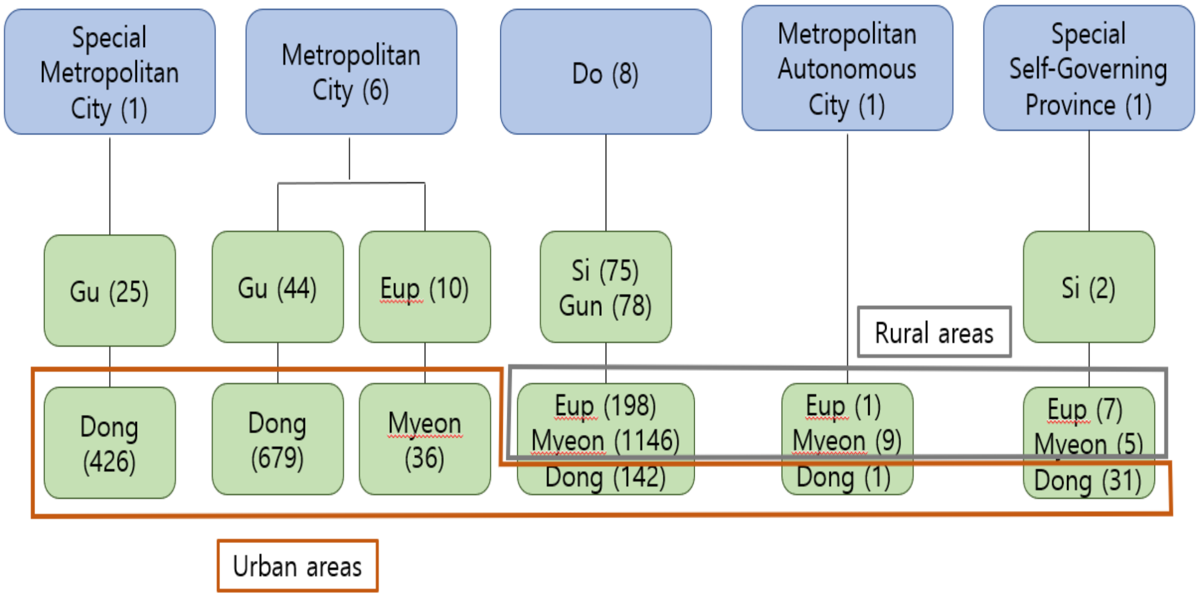

Figure 2. Administration district in Korea: classification of rural and urban areas
* Source: Ministry of Public Administration and Security

The data were adjusted before the analysis. First, the data of a household survey is based on each household and each household has diverse household members. To prevent any distortion induced by impacts of the household sizes on energy consumption[1], income and energy expenditures per household are divided by square root of each household size. Second, for adjusting outliers of the data, households whose energy expenditures are zero and households which use only electricity for energy consumption were excluded from the raw data. In addition, households whose energy expenditures are more than 30% of income were excluded

[1] The most commonly used equivalence scales include OECD equivalence scale, OECD-modified scale, and Square root scale. (1) OECD equivalence scale assigns a value of 1 to the first household member, of 0.7 to each additional adult, and of 0.5 to each child. It had been used in 1980s and early 1990s. (2) OECD-modified scale assigns a value of 1 to the household head, of 0.5 to each additional adult member, and of 0.3 to each child. It was adopted in late 1990s. (3) Square root scale is used in recent OECD publications comparing income inequality and poverty across countries. The publications use a scale which divides household income by the square root of household size (OECD note: What are equivalence scales?)

from this analysis. This is because, in practice, average ratio of fuel expenditures to income in Korea was 5.44% from 2006 to 2015, and even households in the lowest income decile spent only 18.55% of their income during the same period (Yoon & Park, 2016). Following Boardman (1991; 2009) 10%[2] was used to define energy poverty in Korea. Considering all these factors, a conservative estimate of 30% was set as an outlier of the ratio of fuel expenditures. Consequently, the paper uses data of 9,422, 9,251, and 8,541 households in 2014, 2015, and in 2016, respectively.

2.2. Inequality of energy Expenditures

Table 1 shows data for income and energy expenditures by income decile in urban and rural areas of Korea.

2014	income (million won)		energy expenditure (million won)		2015	income (million won)		energy expenditure (million won)	
income decile	urban	rural	urban	rural	income decile	urban	rural	urban	rural
1	362.9	75.1	38.5	9.8	1	391.9	79.9	35.8	8.8
2	704.2	126.5	45.4	11.7	2	710.6	133.6	42.6	11.4
3	968.4	182.4	46.3	12.3	3	974.3	186.8	42.7	11.5
4	1,192.0	246.3	48.1	12.7	4	1,202.1	246.6	45.4	12.6
5	1,412.9	297.0	48.7	13.9	5	1,422.3	298.1	47.4	13.0
6	1,643.1	351.6	51.8	13.3	6	1,644.6	357.9	46.6	11.3
7	1,895.5	415.1	53.0	14.4	7	1,889.4	418.0	48.9	13.4
8	2,213.4	492.9	51.2	14.2	8	2,199.4	488.7	50.3	13.1
9	2,687.5	614.8	54.8	14.3	9	2,682.6	606.1	51.2	13.3
10	4,105.1	944.7	60.5	18.2	10	4,210.0	950.1	59.1	14.9
total	17,184.9	3,746.4	498.4	134.8	total	17,327.1	3,765.7	470.0	123.3

[2] This 10% is from "The Ten-Percent-Rule" of Boardman 1991, 2009.
According to Schuessler (2014: 4-5), competing expenditure-based indicators as follows: The Ten-Percent-Rule (Boardman 1991, 2009), Double Median or Mean indicator (Boardman 1991, Hills 2012), Low Income, High Cost (LIHC) indicator (Hills 2012), and Minimal-Standard indicator (Moore 2012). The Ten-Percent-Rule and Double Median or Mean indicators define energy poverty as excess spending on energy beyond a certain threshold, most prominently, a ten percent share or double median share of energy expenditure for all households relative to net income. By contrast, the LIHC indicator and Minimal standard approaches require minimally adequate consumption requirements.

2016	income (million won)		energy expenditure (million won)	
income decile	urban	rural	urban	rural
1	341.2	73.9	30.8	8.2
2	631.2	122.1	34.8	9.2
3	878.4	171.7	36.8	11.0
4	1,093.0	228.3	37.4	10.6
5	1,300.3	283.2	37.3	10.1
6	1,519.9	336.4	38.9	10.7
7	1,753.3	397.2	40.8	10.8
8	2,048.9	463.7	40.9	11.4
9	2,493.4	576.9	42.0	11.5
10	3,848.2	888.5	48.0	12.5
total	15,907.7	3,541.9	387.8	106.1

Table 1. Income and energy expenditure by income deciles in urban and rural households of Korea

* Data source: household survey of Korea National Statistics Office
*income: average monthly income,
*energy expenditure: average monthly energy expenditures

Figure 3 shows that incomes of urban households were higher than rural households in the same income decile. Furthermore, except in the 1st to 3rd income deciles, incomes of urban households were higher than rural households in any income deciles. Income of rural households in the 10th decile (888.5 million won) was slightly higher than income of urban households in the 3rd decile (878.4 million won). There are no big changes in incomes of rural households in each decile for 3 years. Urban incomes in every decile grew faster than the incomes for rural families throughout the 3-year period.

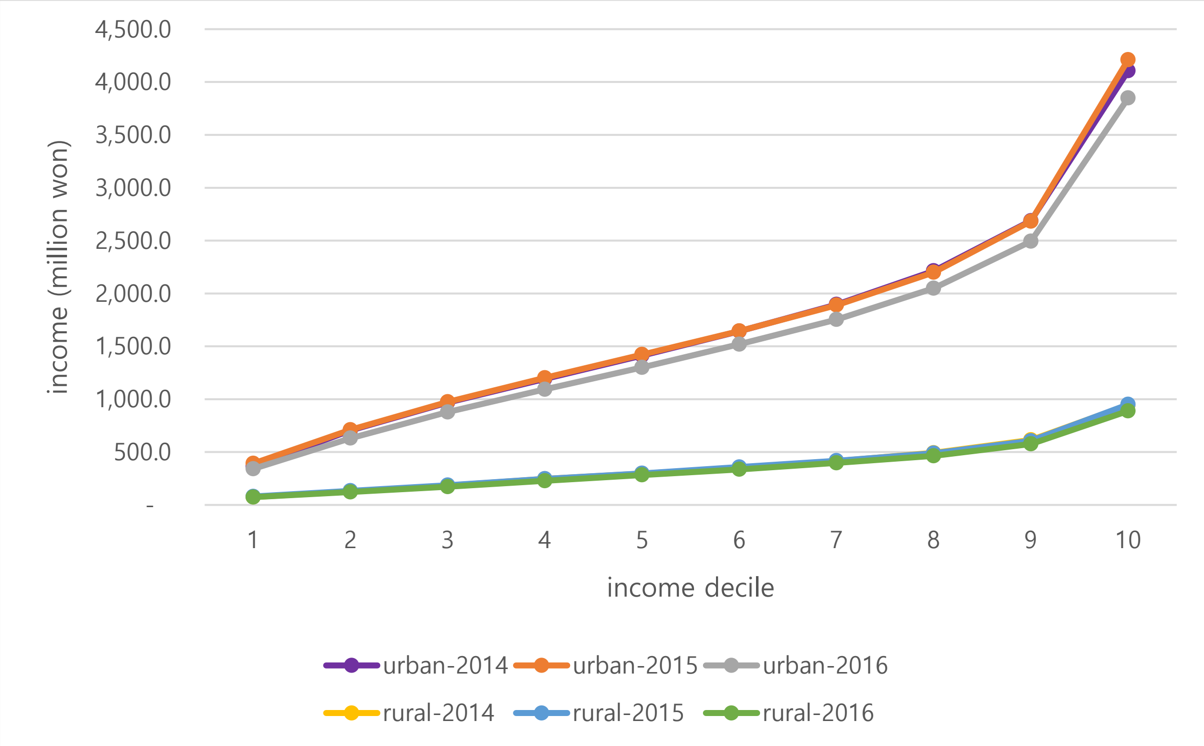

Figure 3. Income of urban and rural households by income decile and year
* Data source: Korea National Statistics Office

Figure 4 shows that energy expenditures of urban households were larger than energy expenditures of rural households in any decile. And, for both urban and rural households, energy expenditures declined over the 3-year- period. The decrease in energy expenditures for urban households was greater than those for rural households. Unlike income in Figure 3, the gap between energy expenditures in the 1st decile and the 10th decile was small. In 2016, energy expenditures of urban and rural households in the 10th decile were, respectively, 1.56 and 1.53 times greater than those in the 1st decile. On the other hand, in the case of incomes in 2016, the gaps were 12.02 times for urban households and 11.28 times for rural households. This shows that the rise in energy expenditures cannot continue limitlessly even if households' income levels continue to increase.

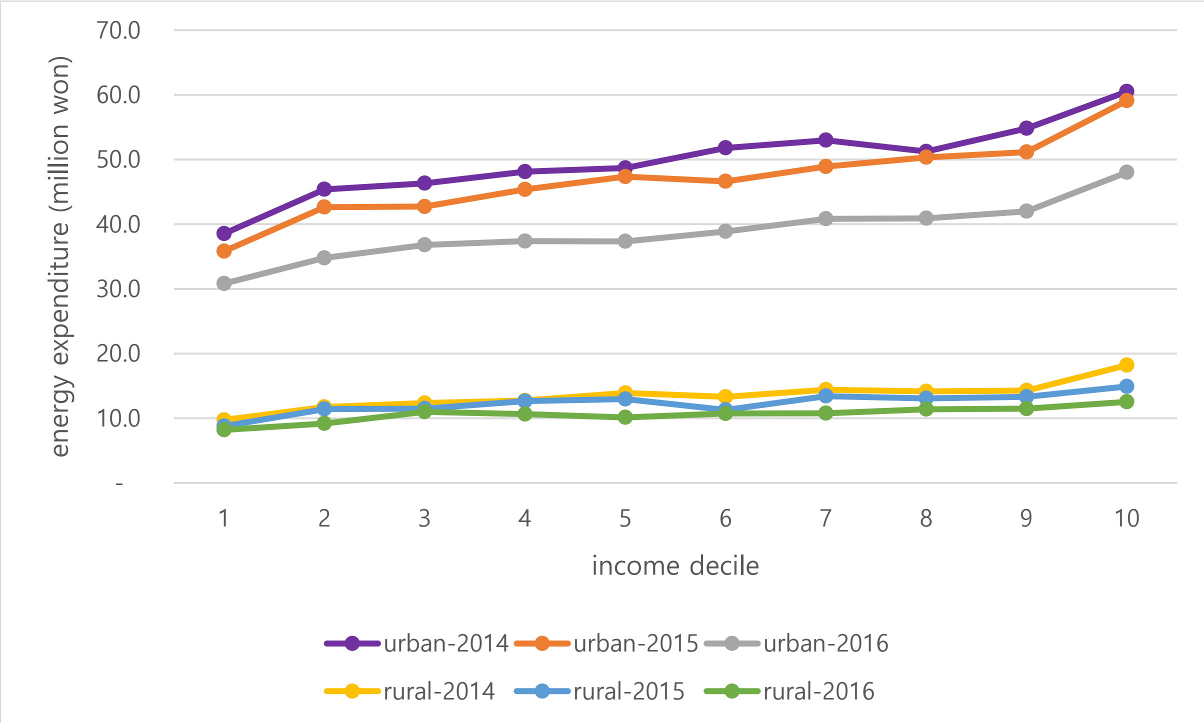

Figure 4. Energy expenditure of urban and rural households by income decile and year

* Data source: Korea National Statistics Office

Table 2 and Figure 5 show the ratio of energy expenditure to income in both urban and rural households.

income decile	urban-2014	urban-2015	urban-2016	rural-2014	rural-2015	rural-2016
1	10.6%	9.1%	9.0%	13.0%	11.0%	11.1%
2	6.4%	6.0%	5.5%	9.3%	8.5%	7.5%
3	4.8%	4.4%	4.2%	6.8%	6.2%	6.4%
4	4.0%	3.8%	3.4%	5.2%	5.1%	4.7%
5	3.4%	3.3%	2.9%	4.7%	4.3%	3.6%
6	3.2%	2.8%	2.6%	3.8%	3.2%	3.2%
7	2.8%	2.6%	2.3%	3.5%	3.2%	2.7%
8	2.3%	2.3%	2.0%	2.9%	2.7%	2.5%
9	2.0%	1.9%	1.7%	2.3%	2.2%	2.0%
10	1.5%	1.4%	1.2%	1.9%	1.6%	1.4%

Table 2. The ratio of energy expenditure to income by income deciles in urban and rural households

* Data source: Korea National Statistics Office

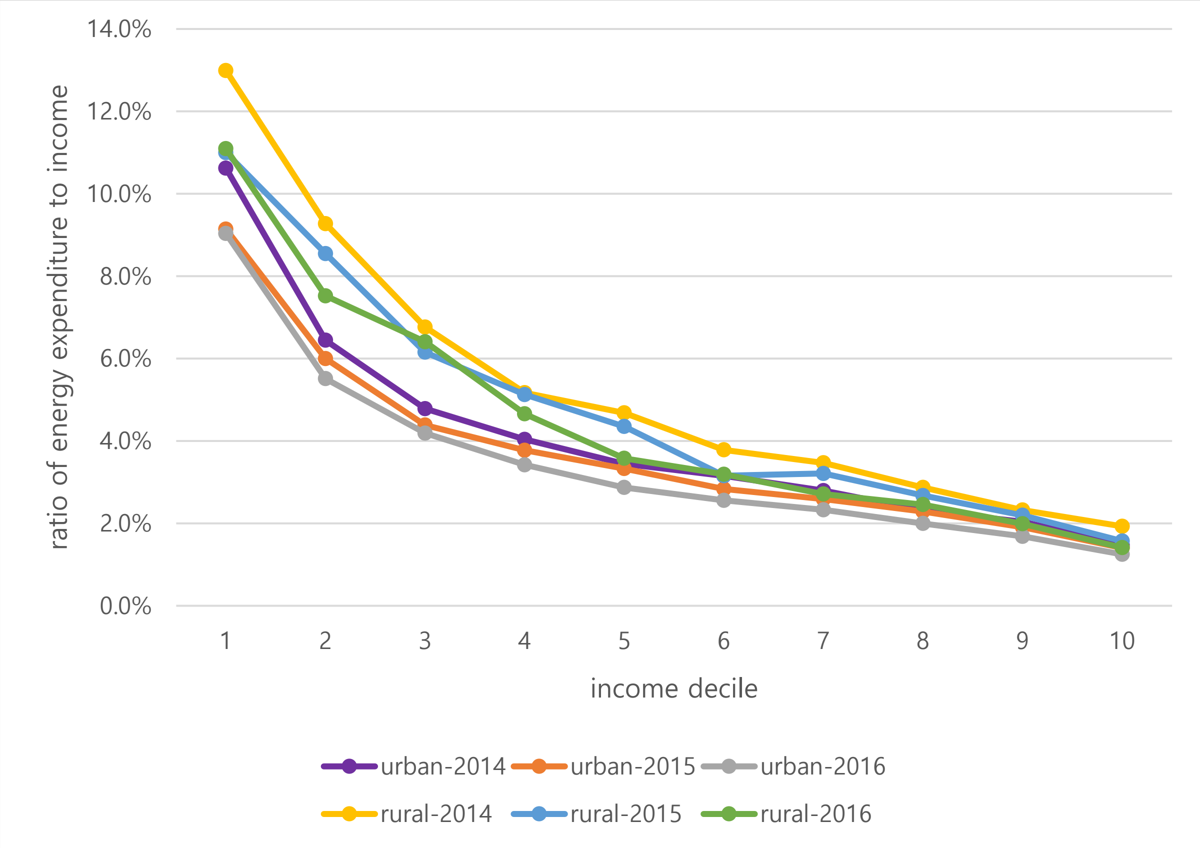

Figure 5. Ratio of energy expenditure to income of urban and rural households by income decile and year

* Data source: Korea National Statistics Office

First of all, the ratio of energy expenditures to income tends to decline in all income deciles over the years. The reduction of the ratio is mainly attributed to decreased prices of energy rather than changes in energy consumption (K.S. Park, 2017: 1). From 2014 to 2016, the prices of kerosene, natural gas, propane and electricity in Korea decreased respectively 39.5%, 31.8%, 20.1%, and 3.0%[3].

3

year	kerosene (won/ l)	natural gas (won/m3)	propane (won/kg)	electricity (won/kWh)
2014	1296.7	947	2112.9	124.9
2015	947.4	792	1801.3	123.4
2016	784.5	646	1689.1	121.2
rate of change	-39.5%	-31.8%	-20.1%	-3.0%

Second, the ratios of energy expenditures to income of rural households were higher than those of urban households in all income deciles and in each year. Poor rural households spend greater portions of their household income on energy than wealthy urban households, not just because their incomes were comparatively less but also because the fuels they consumed were also less efficient than modern fuels (Saghir, 2005: 4). In addition, the ratios declined as income decile increased. That is, the ratios in the 1st decile were the greatest, while the ratios in the 10th decile were the lowest. The ratio of rural households in the 1st decile in 2014 was the highest at 13%.

Third, the ratio gaps between urban-high income and rural-high income households were small. The gap in the 1st decile was 23.3% (rural-2016: 11.1%, urban-2016: 9.0%), while the gap in the 10th decile was 16.7% (rural-2016: 1.4%, urban-2016: 1.2%). This shows that wealthy households face relatively less energy inequality between urban and rural households, compared to poor households

In sum, even though the ratios of energy expenditures to incomes decreased over the years, rural households faced more burden for their energy consumption. And, particularly, poor households faced more severe energy inequality than wealthy households.

2.3. Reasons for the inequality

2.3.1. Electricity vs. other energies

Electricity bills accounted for between 40%-50% of total energy expenditures of households in 2014-2016. Due to the large role of electricity, it should be analyzed whether electricity bills cause energy inequity between urban and rural households.

	2014			2015			2016		
	energy expenditures	electricity	share	energy expenditures	electricity	share	energy expenditures	electricity	share
urban	498.4	202.2	40.6%	470.0	199.3	42.4%	387.8	184.4	47.6%
rural	134.8	59.8	44.4%	123.3	57.0	46.2%	106.1	53.6	50.6%

Table 3. Average monthly energy expenditures and electricity bills in urban and rural areas from 2014 to 2016
* Unit: million won, %
* Data source: Korea National Statistics Office

However, electricity bills are not the main reason for inequity in Korea. First, electricity access is very high and almost evenly distributed throughout the country. That is, electricity is not the cause of the problem for the widening gap in energy access that has resulted in energy inequity. Second, electric tariffs for households are the same across the country. Electricity tariffs are classified as residential, educational, industrial, agricultural, street lighting, and midnight. Both urban and rural households fall in the same bundle of residential tariffs, which means there are no differences in pricing to cause inequitable electricity usages. Even though Table 3 shows the shares of electricity bills of rural households were about 4%p higher than those of urban households in each year, this can be attributed to other impacts rather than electricity tariffs. S.H. Park and J.H. Shim (2013: 48) analyze that a high electricity bill of rural households is due to high portion of old houses and a female householder in rural areas. Consequently, the main reason for the energy inequity arises from differences in energy types except electricity.

Energy inequity appears to result from cooking and heating energies. In Korea, electricity is not a common fuel for cooking and heating. Liquefied natural gas (LNG), liquefied petroleum gas (LPG), and kerosene are usually used for cooking and heating. In the next section, differences of energy types for cooking and heating used by urban and rural households are analyzed further.

2.3.2. Energy demand types and relative prices of the energies

Urban households in Korea depend on LNG for both cooking and heating. LNG expenditures of urban households account for about 80%. The second greatest one is district heating, but the portions are less than 10%. On the other hand, rural households consume more diverse sources of energy than in the urban areas. For rural households, LNG is the most important energy source. But the LNG portion for rural households is only 40%, which is the half portion for urban households. The second energy type is kerosene, and its portion is very similar with LNG portion. Lastly, the third energy type is LPG, which is usually used in a cylinder form.

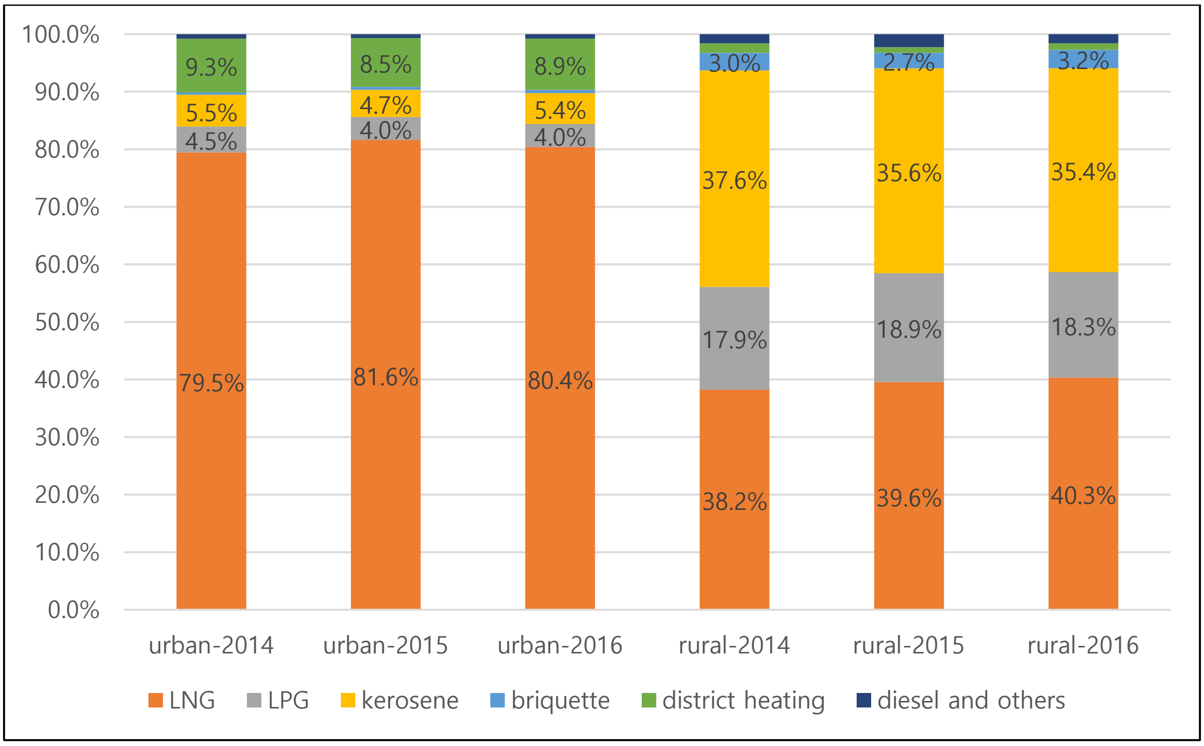

Figure 6. Portions of energy expenditures excluding electricity

* Data source: Korea National Statistics Office

Compared to LNG, LPG in a cylinder and kerosene is very expensive in Korea. Table 4 shows the prices per MJ of LPG in a cylinder and kerosene relative to LNG. Price per MJ of LPG in a cylinder is 86.7% higher than the price per MJ of LNG, and price per MJ of kerosene is 12.6% higher than the price per MJ of LNG. Consequently, rural households pay more money per unit for cooking and heating.

	LNG	LPG in cylinder	Kerosene
after-tax price	792.76won/㎥	1,711.1won/㎏	753.4won/ℓ
price/MJ	18.18won	33.95won	20.47won
% compared to LNG	100	186.7	112.6

Table 4. Prices of LNG, LPG in cylinder and kerosene in Korea

* Data Source: Ministry of Trade, Industry and Energy of Korea (March, 2016)

2.3.3. Imbalanced natural gas penetration

The question that arises is why are rural households are not using cheaper energy sources such as LNG?, Urban households use this lower-cost fuel at a higher rate than rural families, which appears to be a factor in the observed energy inequity discussed in section 2.2. Why do these rural households depend on expensive LPG in a cylinder and kerosene, even though they have comparatively lower incomes than urban households? According to the household surveys, in practice, rural households account for only 10% of total households using LNG.

The main reason for this disparity is the limited distribution of natural gas pipelines in rural parts of the country. Figure 7 shows a map of the main natural gas pipelines in Korea. Korean government determines schedules and places for the construction of natural gas networks[4] by establishing a long-term natural gas demand and supply plan. After the main pipelines are constructed, local gas companies establish their supply plans including construction of supply and retail natural gas pipelines. According to the 12th long-term natural gas demand and supply plan established in December 2015, Korean government plans to construct additional 845km main pipelines by 2023. As a result, total length of natural gas main pipelines of Korea will be 5,305km by 2023. This plan cost estimated about 2.2 billion USD from 2015 to 2023.

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[4] Article 18-2 of Urban Gas Business Act is a legal ground of LNG main pipelines. According to the act, Ministry of Trade, Industry and Energy of Korea shall establish, every two years, a long-term natural gas demand and supply plan spanning more than ten years including the relevant years. And the plan includes efforts for expansion of urban gas such as plans for the construction of natural gas pipelines.

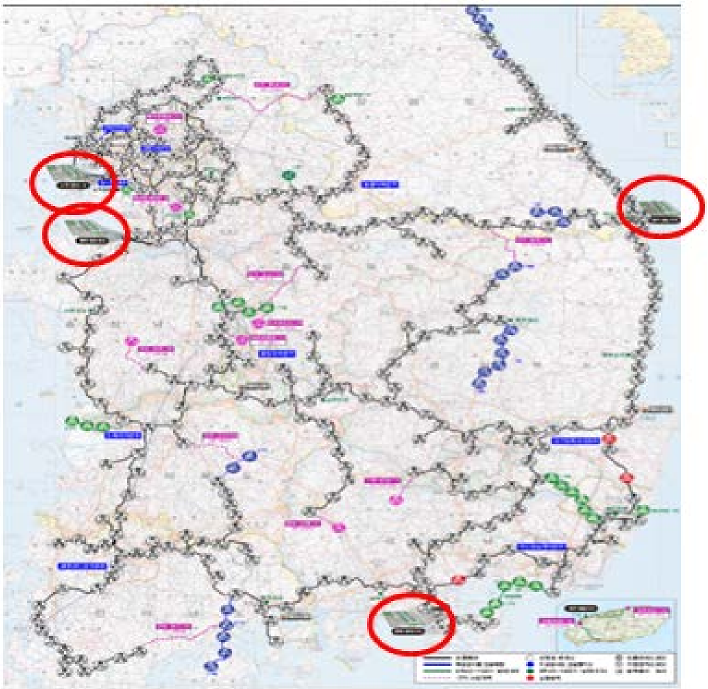

Figure 7. Natural gas main pipelines in Korea

* The black lines are working now, and the blue line is planned to be constructed by 2023.

* Red circles are LNG storage facilities.

* Source: Korea Gas Corporation

Figure 8. Example: An area of natural gas supply pipelines in Korea.

* The black line is a main pipeline.
* The pink line is a supply line to be constructed. And the red pipeline is working now.
* Source: Korea Gas Coorporation

Figure 8 shows a map of natural gas supply and retail pipelines. The supply and retail natural gas pipelines are invested in terms of mainly expected profits of the local gas supply companies. So, if some areas are expected to spend too much construction costs or to have low consumption of natural gas due to low population, the areas are likely to be excluded from investment decisions of private gas companies. Imported LNG to Korea arrives at four storage facilities and is distributed to wholesale consumers through the main gas pipelines. Only after local gas supply companies transport natural gas to retail consumers through retail pipelines, households can access the gas for cooking and heating. That is, even though Korean government establishes a plan for LNG expansion, whether or not households can use LNG depends on the presence of a robust investment plan of expanding local gas facilities at the local level.

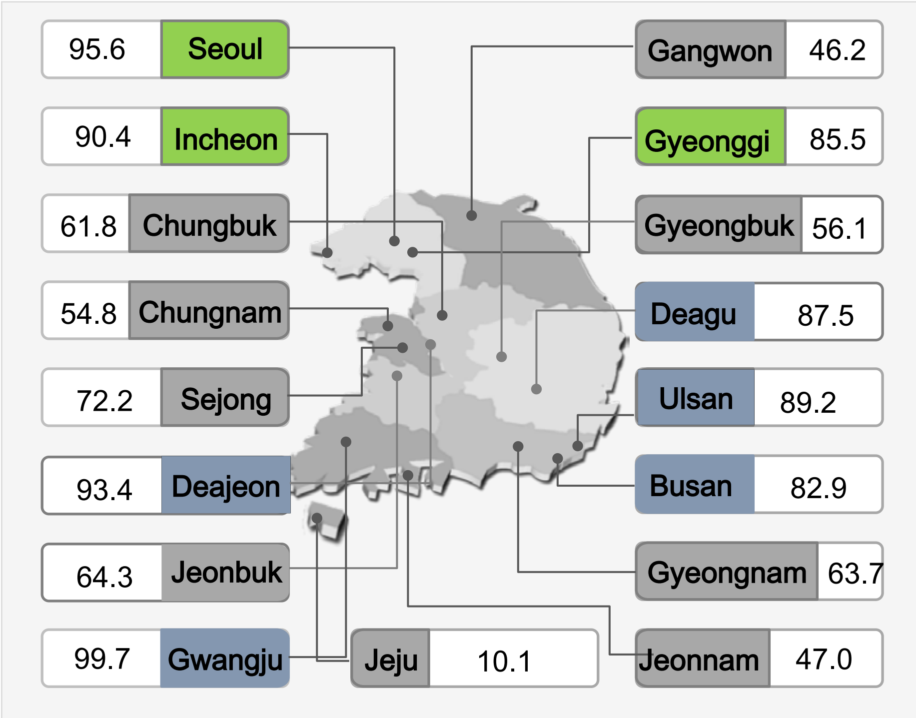

Figure 9. Natural gas penetration rates by provinces in Korea

* Source: Korean City Gas Association

Investment of local gas supply companies is concentrated in provinces with high population density. Total natural gas penetration rate in Korea is about 79.4% (Korean City Gas Association, 2014). The penetration rate is defined as the number of households demanding natural gas dividend by the number of total households in each province. Noticeablly, the penetration rate of metropolitan cities in Korea is 90.5%, while the rate of other local provinces is only 52.9%. In Figure 9, Seoul, Gyeonggi and Incheon are capital areas, which are major metropolitan cities, and those have very high natural gas penetration rates. The other six metropolitan cities, including Daejeon, Gwangju, Busan, Ulsan, Daegu have high natural gas penetration rates.

In addition, decisions by the local gas supply companies for construction of LNG infrastructures is manly determined by the construction costs of the project. Jeju and Gangwon have very low natural gas penetration rates, mostly due to geological factors. Jeju is an island and Gangwon has a lot of mountain, making construction costs per km of gas network very exorbitant. As a result, areas with these high construction costs of gas pipelines have been excluded from investment in expansion of the local gas facilities.

2.3.4. The relation of natural gas penetration rates and households' income

Table 5 shows data classified by household use of natural gas. Households using natural gas account for about 80% of the total households, which is very close to total natural gas penetration rate of 79.4%, as researched by Korean City Gas Association in 2014. Households using natural gas are mostly found in the urban areas. The proportion of urban households using natural gas is nearly 90%. In addition, income of households using natural gas is about 5 times higher than others. From Table 5, it is evident that high natural gas penetration exists in areas with relatively high income level, mostly urban settings.

	LNG use	the number of households (portion)	income (million won)	energy expenditures (million won)	% of urban households
2014	use	7462(79.2%)	17,370.5	495.1	89.9%
	no use	1960(20.8%)	3,560.7	138.1	44.0%
2015	use	7343(79.4%)	17,409.3	469.0	90.0%
	no use	1908(20.6%)	3,683.5	124.3	42.8%
2016	use	6851(80.2%)	16,249.1	390.0	88.8%
	no use	1690(19.8%)	3,200.5	103.8	44.1%

Table 5. The number of households classified by LNG usage and their income, energy expenditures and portion of urban households in each classification

* Data source: Korea National Statistics Office

The relationship of natural gas penetration rates and household incomes of each province can be inferred[5] indirectly.

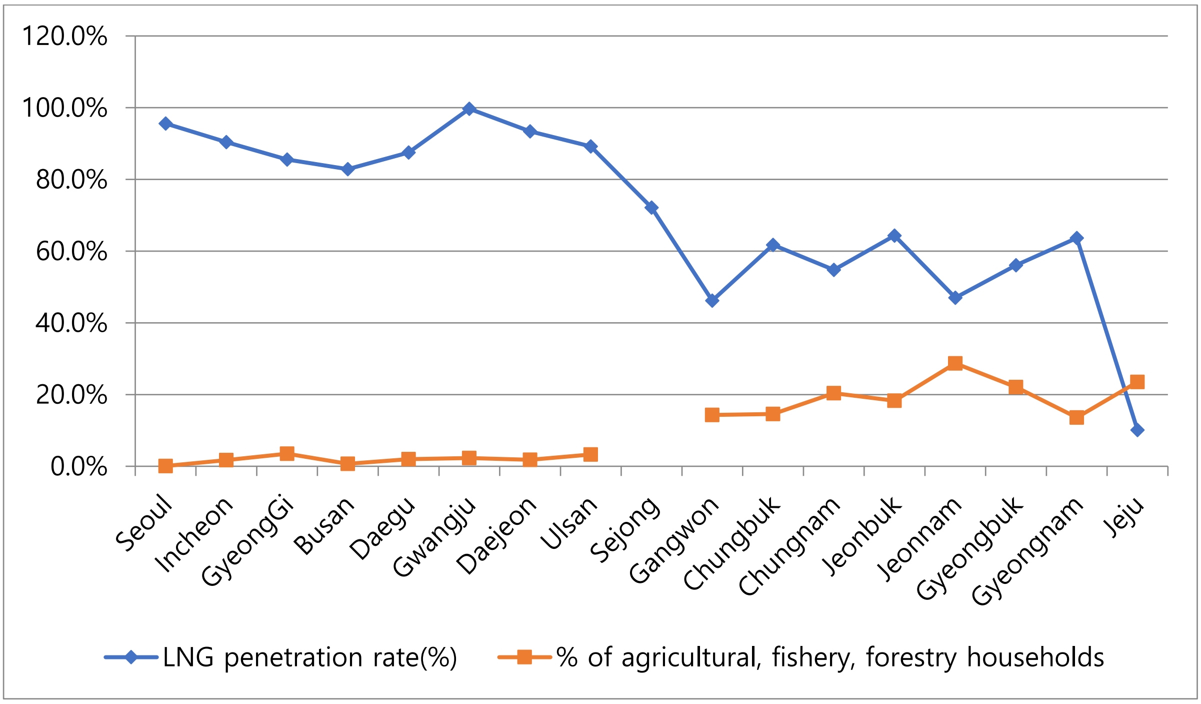

Figure 100. Relation of natural gas penetration rate and percentage of agricultural, fishery and forestry households

* Data sources: Korea National Statistics Office, Korean City Gas Association, Korea Rural Economic Institute

* Sejong is a new city, so that data regarding the number of agricultural, fishery, and forestry households is not researched.

Figure 10 shows the relationship between natural gas penetration rates and the percentage of agricultural, fishery and forestry households in each province of Korea. There exists an inverse relationship between natural gas penetration rates and the percentages of agricultural, fishery and forestry. Metropolitan cities with a low ratio of agricultural, fishery and forestry households have a high natural gas penetration rate (such as Seoul, Incheon, GyeongGi, Busan, Daegu, Gwangju, Daejeon and Ulsan). On the other hand, rural provinces with a high ratio of agricultural, fishery and forestry

[5] Specific provinces of each household in the household surveys are not open to the public. So, it is impossible to analyze the direct relation between households' income and natural gas penetration rates of each province based on the household survey.

households have a low natural gas penetration rate (such as Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam, and jeju). Income of agricultural, fishery and forestry households is only 57.2% of income of urban worker's households. Consequently, due to this unequal income distribution and natural gas penetration rates by provinces, the study concludes that rural households with low income experience challenges in accessing cheap natural gas options for their domestic use because of poor natural gas supply network.

2.3.5. Findings

Rural households have lower incomes than urban households. As a result, rural households have a greater burden than urban households with high income with regard to payment of their energy expenditures. Furthermore, a serious problem of inequality exists among deciles of household incomes even in the same rural areas.

Access to electricity and tariff structure in both urban and rural households are almost similar. Rural households depend on relatively expensive LPG in a cylinder and kerosene, whereas urban households almost exclusively depend on cheap LNG. This difference of energy types results from unequal natural gas penetration in Korea. Consequently, energy inequity in Korea results from imbalanced LNG infrastructures between urban and rural areas.

3. A current policy to alleviate energy inequity and assessment of the policy

3.1. Policy overview: A LPG storage tank project

To alleviate the energy burdens of rural households, Korean government designed the LPG storage tank project. The project seeks to construct LPG storage tank and pipeline facilities in small villages across rural parts of the country for easy and convenient supply of LPG. A government and local gas supply companies install a small LPG storage tank and pipelines. And government gives subsidies to households to substitute kerosene-fueled boilers to gas-fueled boilers. Under this program, Korea central government pays for 50% of total costs and local government pays for 40% of costs of the projects, while the residents of the villages pay for only 10% of the costs. Local residents own the installed LPG facilities and take the lead in management of the project, including selection of gas company and facility maintenance strategies.

- ✓ Key players: Korean gov't, rural gov't, residents, local gas companies
- ✓ Installed facilities: LPG small storage tanks and pipelines, gas boilers
- ✓ Cost distribution: Korean gov't (50%), rural gov't (40%), residents (10%)
- ✓ Ownership of the facilities: residents
  - Local residents take the lead in the project such as selection of gas companies and facilities maintenance strategies.
- ✓ Maintenance: LPG companies

  Residents depute maintenance and repair of facilities to LPG companies.

Figure 11. Main contents of a LPG storage tank project

* Sources: Ministry of Trade, Industry, and Energy in Korea

Figure 12 illustrates a picture of a small village participating in the LPG project. The number of households in the village is only 69. In the middle of the village, one

LPG storage tank whose capacity is 2.9 ton was installed. Also, the length of the total pipeline network is about 1.7km.

Figure 12. A landscape of Samgok-ri, Chungbuk
* Sources: Ministry of Trade, Industry, and Energy in Korea

Figure 13 shows pictures of LPG storage tanks, supply pipelines and retail pipelines installed in a local village. These facilities are connected by one central control system for all the participating villages.

Storage tanks	
Supply pipelines	
Retail pipelines	

Figure 113. LPG storage tanks, supply pipelines and retail pipelines.

* Sources: Ministry of Trade, Industry, and Energy in Korea

3.2. Evaluation of the LPG storage tank project

3.2.1. Methodology: E4 framework

This paper uses an E4 framework developed by Wang et al. (1992 and 1996) and improved in 2010 (Wang, 2010). It is used to assess the LPG project in terms of sustainability. Wang et al. (1992) pointed out problems of political economy which considers sustainability as a mere technical and economic matter. The problems are that this kind of political economy causes nature's unsustainability and inequality between rich and poor countries. In this light, they emphasized to restructure social relations of energy, environment and development ecologically and equitably. The improvement in 2010 produced an E4 framework that is anchored not only on strong sustainable development (SSD) principles but includes political ecology as a component. SSD is a sustained development and qualitative improvement, where the economy and nature are considered to be complementary to each other (Nilsen, 2010: 497). Political ecology is a proposal to understand environmental problems in connection with political and economic contexts and to emphasize close relations of economy, energy, equity and environment (Raymond and Bailey, 1997: 28, Byrne et al., 2009: 84). Especially, it focuses on 'the point of view of local people, marginal groups, and vulnerable populations' (Robbins, 2014: 12), which is reflected in the 'equity' component of the E4 framework (Wang, 2010).make effects on environment.

3.2.2. Evaluation in terms of energy

This project has positive impacts on a village participated in this project, while it has negative impacts over Korea. First, with regards to each village participated in the project, households can use an energy for cooking and heating more stably. Households don't have to worry about the lack of fuels for cooking and heating any more. Before this project, each household had to order kerosene or LPG in a cylinder before the fuels are finally run out. They had to check their consumption and residue of fuels, and they had no choice but to experience discomfort in the case when they forgot to order fuels or delivery of fuels was delayed. However, after this project, they don’t need to check the residue of LPG in a storage tank and order it by themselves. It is implausible for LPG to be delivered late. LPG is managed by professional gas companies contracted with the village and can be supplied very stably through pipelines

In contrary, with regards to Korea as a whole, this project could make a little negative impact on energy security. As a result of this project, consumption of kerosene would decrease, and consumption of LPG would increase. This is because kerosene as a main fuel for heating in rural areas can be switched to LPG. Domestic consumption of LPG is 5.5 times more than domestic production, whereas domestic consumption of kerosene is less than domestic production. Consequently, this project could make Korea import more LPG, which worsen energy independence and energy security of Korea as a whole.

(Unit: 1,000 bbl)	Domestic production	Domestic consumption	Import	Export
Kerosene	18,493	16,227	10.67	3,769
LPG	25,366	89,866	62,712	65
Ratio (LPG/kerosene)	1.37	5.54	5,877.41	0.02

Table 6. Domestic production, consumption, import and export of Kerosene and LPG (2015)

* Source: Statistics of petroleum products kept by Korea Petroleum Information Network. See http://www.petronet.co.kr/main2.jsp

3.2.3. Evaluation in terms of economy

This project can reduce a retail price of LPG. This is because this project simplifies LPG distribution structures. Generally, LPG in a cylinder is distributed by four steps: a supplier (importer, oil company) -> a LPG station -> a sales store -> a customer. But the LPG station and sales store steps can be omitted through this project. Table 7 shows real prices in a small village in which this project was implemented. Cost of LPG supplied by a storage tank and pipelines is about 50% lower than that of the LPG supplied by a cylinder.

Of course, this project also changes from cheaper kerosene to more expensive LPG. However, price of kerosene is higher than price of LPG supplied by a tank and pipelines. In addition, considering only half price relative to LPG in a cylinder and social cost of CO_2, even though kerosene price is about 50% lower than LPG in a cylinder, this project can reduce total social energy costs of rural households. The social costs of CO_2 used by U.S. Environmental Protection Agency (EPA) is $36/short ton, and Ackerman & Stanton (2012) argue the costs reach an astounding $900/t$CO_2$ in 2010.

	LPG supplied by a cylinder	LPG supplied by a tank and pipelines
Price	1,711.1won/㎏	829.0won/㎏
Comparison (LPG supplied by a cylinder=100)	100	48.5

Table 7. Comparison between LPG supplied by cylinders and by pipelines
* Source: Ministry of Trade, Industry and Energy of Korea (March, 2016)

3.2.4. Evaluation in terms of environment

As mentioned above, this project makes rural households change fuels from both kerosene for cooking and LPG in a cylinder for heating to LPG supplied through a storage tank and pipelines. First, in terms of switch from kerosene to LPG supplied through a storage tank and pipelines, this project can reduce CO_2 emissions. This is because the CO_2 emission coefficient of kerosene is 71,900 kgCO_2/TJ, while that of LPG is 64,500 kgCO_2/TJ.

Second, in terms of switch from LPG in a cylinder to LPG supplied through a storage tank and pipelines, an environmental effect of this project makes sense when life cycle analysis is conducted. Life cycle analysis is a method to examine all stages in using resources from energy production to consumption (Epstein et al, 2011:73). Based on this method, LPG supplied through a storage tank and pipelines has a strength relative to LPC in a cylinder. Thank to this project, cylinders for LPG don't need to be produced. A storage tank substitutes the lots of small cylinders. And a current rubber hose connecting a LPG cylinder to a gas stove don't need to be used. Instead of the rubber hose which should be changed periodically, metal pipe having longer life time can be used. Also, the times of delivery can be reduced, energies needed for the delivery also can be reduced. Consequently, by reducing use of subsidiary materials and the times of delivery for LPG consumption, CO_2 emissions created at the production and delivery process of the materials also can be reduced.

In addition, it can be said that Korean government implemented the LPG project with an anthropocentric view. Korean government considers the LPG project as a measure to resolve claims of rural communities for construction of natural gas pipelines. This approach is based on the thought considering nature as merely natural resources. And this view is based on the Promethean perspective and corresponds to political economy which Wang et al. criticized in 1992. Promethean perspective considers a human as a superior entity than nature. The perspective denies environmental limits and thinks that the supply of natural resources is infinite because there is no fixed supply of resources (Dryzek, 2013: 52, 59, 63).

3.2.5. Evaluation in terms of equity

As the result of evaluation of an economic aspect, rural households can save energy expenditures. The saved expenditures can be used for other purposes, which can improve standard of living of rural households. Also, this project improves their inconvenience regarding energy consumption. Before the LPG project, rural households should check the remained LPG in a cylinder and kerosene, and they should order those energies periodically. After the LPG project, they don’t need to manage those energies by themselves, because professional gas companies cover those things. In addition, this project can decrease accident risks so that it helps rural households live more safely. Usually LPG accidents occur when gas is charged to cylinders. Due to a storage tank and pipelines, the number of storage can be declined. Table 8 shows a reducible accident risk in LPG charging process, comparing a cylinder for LPG to a storage tank for LPG with the same capacity.

Storage type	# or storage per year	Ratio
Facilities with five 50Kg LPG cylinders	365	5
Storage tank (250kg)	73	1

Table 8. Comparison between LPG supplied by cylinders and by pipelines in safety aspect
* Source: Korea Gas Safety Corporation

Gas facilities can be improved more safely. Metal pipes are safer than rubber horses. The metal pipes can't be torn and melt. Also, professional gas supply companies manage all of the facilities on their duty. Consequently, total reduced extent of accident risks can be greater and rural households can live safely as much as urban residents at least in terms of energy use.

Figure 124. Increased safety resulted from the LPG project
* Source: Ministry of Trade, Industry, and Energy in Korea

Furthermore, the process of the project is followed by a democratic decision-making process through the participation of rural households. This point corresponds to an aspect of political ecology which is emphasis of 'policies that empower community-scale decisions regarding ecosystem access and use' (Byrne and Glover, 2002: 19). For example, the project is implemented only in the villages where most households agree on the project, even though the LPG project are initially designed by a central government. Because the project is run by village, the projects can be revised easily depending on specific conditions of each village. And, the households have a right to select the best local gas companies to support them. Also, central and local government, rural communities, and local gas companies are participated in the LPG project. In this respect, the LPG project can be assessed positively based on the democratic pragmatism[6].

3.2.6. Findings

This project seems to nearly satisfy the E4 framework.. In addition, this project has the following positive features: decentralization, convenient and safe energy use, and consideration of the poor rural households and women. In this vein, the LPG project seems to be a good solution to mitigate the energy inequity. However, the lack of an ecological thought is a crucial drawback of the LPG project. The LPG project is still based on the anthropocentric thought.. It makes sense to say that the LPG project is superior to a situation where rural households use LPG in a cylinder and kerosene. Even when a method of LPG use is changed that makes it cheaper, safer, and more convenient, dependency on LPG still follows a hard energy path introduced by Lovins (1977). The hard energy path is an energy structure and a practice depending on “hard” technologies which mean centralized high technologies like fossil fuels. And the hard energy path aims to increase energy supply (Lovins, 1977: 77). The problem is that a society following the hard energy path can’t be developed sustainably in the long run.

[6] Democratic pragmatism assimilates to the ‘decentralized networked governance’ (Dryzek, 2013: 109). Under the democratic pragmatism, all people such as citizens, NGOs, and corporations are intended to participate in social problems and cooperate each other.

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However, it is not reasonable to argue that the LPG project should be stopped right now because it fails to solve issues of long-term impacts. Karekezi and McDade (2011: 155) argue that, in the near term, cleaner fossil fuels such as LPG reduce a host of social, economic, and environmental barriers to overcoming poverty due to higher combustion efficiency, even though wide-scale deployment of renewable energy systems may provide the best options for providing access to cleaner and modern energy options while ensuring long-term sustainability. In this light, while keeping the LPG project as a policy option, the supplementation in terms of the more ecological view should be suggested as a policy proposal.

4. Policy recommendations

4.1. Current policies

The Korean government has implemented diverse policies to alleviate energy inequality by supporting low-income households. Broadly, there are three categories of the policies: income support, price support, and energy efficiency support. First, with regard to income support for low-income households, major policies are as follows: cost of living assistances including energy expenditure[7]; provision of fuels[8] to

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[7] (Article 7.1 of National Basic Living Security Act) The kinds of assistances under this Act shall be as follows: Cost of living assistances; Housing assistances; Medical care assistances; Educational assistances; Childbirth assistances; Funeral assistances; and Self-support assistances.

[8] (Article 9.1 of Emergency Aid and Support Act) The types and details of aid provided for in this Act are as follows: Subsidization, by cash or in kind, for expenses of providing fuel or covering costs necessary for overcoming a critical situation.

help people overcome hardships in livelihood or critical situations due to any cause or event; and provisions of an energy voucher[9] for low-income households in winter. Second, with regard to price support for low-income households, bills of electricity, LNG and thermal energy can be discounted for low-income households, the disabled person, households with three or more children, etc. Lastly, with regard to energy efficiency support, heat insolation and supply of high efficiency lights, etc., can be implemented for low-income households (Y.K.Jung and G.S.Park, 2013:3-18).

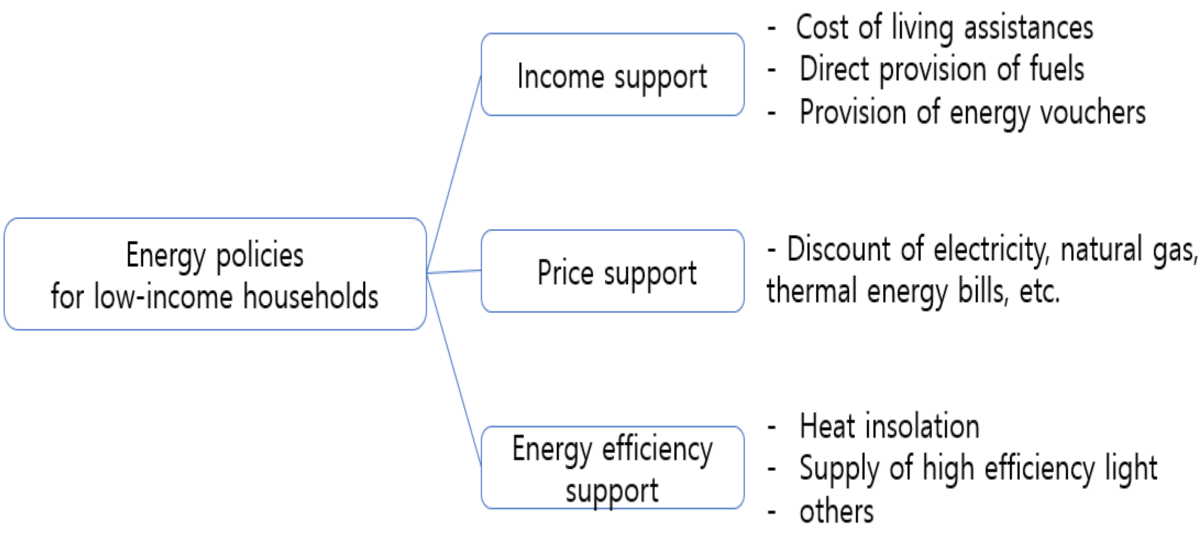

Figure 135. Energy policies for low-income households in Korea
* Source: Y.K.Jung and G.S.Park, 2013

However, the policies are applied for all low-income households, not for only rural households. So, even though rural households should pay more for cooking and heating energy than urban households in the same income decile, if the rural households don't have low income, the households are excluded from the target of

[9] (Article 16-2 in Energy Act) For the universal supply of energy to all people, the Government may conduct projects to support the following matters (hereinafter referred to as "energy welfare projects"): 1. Supply of energy to vulnerable classes in energy use, such as low-income classes (hereinafter referred to as "vulnerable class in energy use")

the policies. So, there is still energy inequity between rural and urban households. H.J.Lee et al, (2013: 29) indicates inequity problems of current policies. According to their argument, households which live in areas without natural gas pipelines so that use relatively expensive kerosene and LPG in a cylinder are likely to be excluded from the policies' support target. In addition, the above policies are affected by government income. So, it is not sure that the policies keep going.

In this light, it is worthy to investigate which policies can be set directly for rural households facing energy inequity, and which policies can resolve the energy inequity in the long term regardless of government income. As the first policy option, subsidy method is investigated, and revision of a current subsidy program is proposed. And, as the second policy option, a renewable energy is proposed.

4.2. Subsidy

A subsidy program for rural households can be discussed to alleviate energy inequity. Shue (1999) argues when inequality already exists, an unequal distribution can be justified. As methods for provision of subsidy, traditional cash assistance, in-kind aid, and energy vouchers can be used. Each method is investigated as follows

4.2.1. Traditional cash assistance

Korean government can give some amount of cash to rural households living in areas where LNG pipelines are not constructed. The amount of the subsidy should be enough to diminish the energy inequity resulted from impossible access to LNG.

Direct cash transfer has both advantages and disadvantages. Levine and Bailey (2015: 8) argue that direct aid in the form of cash is often a highly effective way to reduce suffering, and to make limited humanitarian aid budgets go further. They mention that cash transfers to people usually needs less costs than in-kind assistance, because aid agencies do not need to transport and store relief goods. On the other hand, Peppiatt et al, (2010; 14-16) indicate that the liquidity of cash can make cash transfers available for uses for which the transfer was not intended. For example, a beneficiary can use the cash for other purposes, not for solving energy inequity. And, due to the mobility of cash, cash granted to rural households can be transferred to other people.

In this paper, analysis of J.H. Park (2015) is relied upon. He analyzes the amount of cash transfer and its impacts on energy inequality based on the data in 2014. He sets three kinds subsidies as follows: 1) matching the ratios of the cooking and heating energy expenditures to income of each rural household with average ratio of total rural households; 2) matching the ratios of the cooking and heating energy expenditures to income of each rural household with average ratio of total urban households; and 3) matching the ratios of the cooking and heating energy expenditures to income of each rural household with urban households in the same income deciles.

There criteria are applied to the household survey in 2016. However, rather than energy expenditures for only cooking and heating, total energy expenditures are used for the below analysis in this paper. This is because it makes sense to assume that the lack of access to natural gas makes effects on total energy expenditures of rural households.

income decile	1st criterion		2nd criterion		3st criterion	
	subsidy	subsidy per household	subsidy	subsidy per household	subsidy	subsidy per household
1	5,987,815	35,431	6,399,371	37,866	1,522,465	9,009
2	5,531,412	32,730	6,211,407	36,754	2,457,077	14,539
3	5,859,606	34,672	6,815,308	40,327	3,807,908	22,532
4	3,795,613	22,459	5,066,444	29,979	2,824,400	16,712
5	1,652,652	9,779	3,229,549	19,110	1,999,590	11,832
6	664,675	3,933	2,537,248	15,013	2,131,041	12,610
7	-	-	1,085,182	6,421	1,517,814	8,981
8	-	-	82,206	486	2,127,895	12,591
9	-	-	-	-	1,764,117	10,439
10	-	-	-	-	1,444,888	8,550
total	23,491,772		31,426,715		21,597,196	

Table 9. The amount of subsidy by each criterion
* Data source: Korea National Statistics Office

For the first criterion, averagely 3,933 ~ 35,431 won per month per household is needed for rural households in 1st ~ 6th income deciles. For the second criterion, 486 ~ 40,327 won per month per household is needed for rural households in 1st ~ 8th income deciles. Lastly, for the third criterion, 8,550 ~ 22,535 won per month per household is needed for all rural households. Total subsidy is the greatest for the second criterion.

4.2.2. In-kind aid

Korean government can directly give rural households fuel for cooking and heating. The in-kind aid is a sure solution solving the problem of cash transfer which is possibility to be used for which it was not intended. However, at the same time, the in-kind aid leads beneficiaries to consume more of the good than the usual amount of consumption, so that the main cost of providing benefits in kind is a deadweight loss resulted from the distorting consumptions (Lieber & Lockwood, 2013: 6).

In the case of energy, Korean government exceptionally applies in-kind aid into coal briquette for extremely low-income households in winter. The in-kind aid of briquette is implemented for supporting producers of briquette as well as low income households. However, in the case of LPG and kerosene companies, there is no need to support them. In addition, if this in-kind aid is applied to a program supporting rural households regarding energy usage, there are so many beneficiaries. This means that government should spend significant costs for delivery and storage of the provided energy. Due to the costs as well as deadweight loss, in-kind aid is not good for provision of energy.

4.2.3. Energy vouchers

Korean government can give energy vouchers to rural households. Energy vouchers can resolve the problems of both cash transfer and in-kind aid. Energy vouchers are limited in buying energy, so that it is almost hard for beneficiaries to use the vouchers for which it was not intended. In addition, energy vouchers can be provided to beneficiaries as cards or coupons, so that it needs much less costs for storage and delivery of the vouchers than that of real energies in in-kind aid.

In energy sector, Korean government already has an energy voucher program for low-income households. The energy voucher program was set for energy vulnerable groups such as low-income households, the disabled, the elder, infants, and pregnant women. The voucher is not real money. The voucher can be used for reducing bills for electricity, LNG and district heating, and for direct purchase of kerosene, LPG and briquette. The amount of voucher is different depending on a family size: 84,000 won for single-person household, 108,000 won for two-person household, and 121,000 for above three-person household. And the voucher should be used within 7 months.

4.2.4. Findings

The energy voucher system may be the most effective subsidy method to support rural households in Korea. First of all, traditional cash transfer can cause controversy when government announces to give cash transfer to rural households. Urban households must oppose the cash transfer to rural households. They may think that the subsidy program is unfair because only residential districts decide whether or not people can get the subsidy. That is, it is very hard for government to persuade urban households. In addition, cash transfer is not effective for extremely low-income rural households. Extremely low-income households facing a high energy burden consume less energy than the minimum energy level required to maintain health and well-being. For such households, in-kind or energy vouchers rather than traditional cash assistance may be more effective for resolving energy problems (Y.K.Jung & G.S.Park, 2013: 67).

Second, compared to voucher, in-kind aid needs more costs to provide subsidy to rural households. The in-kind aid makes government pay for storage and delivery. And it limits beneficiaries to buy energy in more cheap prices. That is, even though both the in-kind aid and the voucher help beneficiaries use energies through a government support, the energy voucher is more cost-ineffective way.

Consequently, an energy voucher is the best options. Just, for more direct support for rural households, I recommend that the current voucher program adds a residential district as a criterion of support. If applicants live in rural areas, the applicants can receive an advantage in a screening process, which helps rural households can be selected as beneficiaries of the voucher program.

4.3. Renewable energy

Renewable energies can be a cost-effective and reliable alternative in addressing rural livelihoods energy requirements (Byrne et al., 2007). Byrne et al. (2009: 81) suggest a community-scale renewable energy, not a mega-scale renewable energy, for sustainability and environmental justice. Especially, as a community-scale renewable energy, they suggest a sustainability energy utility which helps communities 'reduce use of obese energy resources and reliance on obese energy organizations' (Byrne et al., 2009: 88). In this light, small scale renewable energies are analyzed in this chapter.

4.3.1. Premise for an analysis

4.3.1.1. Direct and indirect solutions

Energy inequity between urban and rural households is resulted from a difference of access to natural gas. And the lack of access to natural gas of rural households makes effects directly on energy consumption for cooking and heating, and indirectly on electricity consumption. For example, when rural households should use expensive kerosene for house-heating, they can use more electricity for heating than households which can use cheap energy for heating. To resolve the direct impacts, solutions in terms of cooking and heating energies should be analyzed. In practice, the LPG project is turned out as a realistic solution. However, as mentioned above, this paper intends to search more environment-friendly and long-term solutions for energy equity. Among renewable energies, a solar thermal air-heater or water-heater can be alternatives for the LPG project. In addition, a small-scale biogas facility can be used for heating and cooking in rural areas. Especially, for farms which should deal with livestock manures, its effectiveness can be significant. It can supply heat for rural households by replacing fossil fuels, and it can be usually be integrated into a sustainable farming systems for reduction of greenhouse gas emissions and pollution to land, air and water (Lukehurst and Bywater, 2015; 40).

At the same time, indirect solutions can also be analyzed. As the indirect solutions, this chapter analyzes the renewable energies which can reduce total energy expenditures of rural households increased by the lack of access to natural gas, not only cooking and heating energy expenditures. This is because complete changing energies for cooking and heating from current LPG and kerosene to electricity generated by renewable energies is not realistic. For the complete changing, all boilers and stoves should be changed to electric ones, so that dependency on electricity of rural households increases. High dependency on electricity can let rural households pay more energy expenditures because they can be applied to higher electricity tariff in the current progressive electricity tariff scheme due to instability of renewable energies.

4.3.1.2. How much electricity should be generated by renewable energy facilities for the indirect solutions?

Before comparing renewable energies, an adequate capacity for renewable energies should be determined. It is assumed that the adequate capacity covered by renewable energies for rural households is to the extent which energy inequity is resolved between urban and rural households at the same income level. In this paper the capacity is determined according to the third criterion in chapter 4.2.1. This is because the first criterion is only a solution improving inequality among rural households. And, I think that the second criterion is giving too much benefits to rural households than the extent resolving energy inequity between urban and rural households. In this light, renewable energies should reduce energy expenditures of 12,623 won[10] per month. The average revenues per kWh sold in 2016 is 121.52 won/kWh (Electric Power Statistics Information System, 2016). So, electricity consumption for 12,623 won is 103.87kWh. For each household, renewable energy facilities should generate 103.87kWh per month and 3.46kWh per day. A specific capacity can be determined depending on efficiency of each renewable energy facilities.

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10 $\frac{21,597,196}{1,711} = 12,623$, Here, 21,597,196 is total subsidy and 1,711 is the number of rural households in 2016 data.

4.3.2. Available options

4.3.2.1. Small-scale solar Photovoltaic (PV)

Figure 146. Residential solar PV
* Source: NREL image gallery

Advantages and Disadvantages

Solar power is generated by turning energy in the sun's light into electrical energy. It does not emit pollutants and greenhouse gases. Systems can be installed without no moving parts, reducing maintenance costs. Of course, Solar PV has drawbacks. First, resource availability depends on the time of day, seasons, and the weather. However, solar PV connected on existing grid can secure stability. Second, the efficiency of solar PV modules is low compared to those of traditional fossil fuels or nuclear power plants. However, the efficiency has increased in absolute terms over the past ten years. For example, crystalline silicon PV modules are not only the most efficient, but saw the greatest absolute increase in efficiency from around 15% to almost 21% in 2012 (IRENA, 2014: 83).

Solar PV potential in Korea

Figure 18 represents global horizontal irradiation distribution. It has different values depending on areas. Generally, south areas have better solar radiation. Average solar irradiation is 3.7 $kWh/m^2/day$. Mok-po and Jin-Ju have the most solar radiation, respectively, 3.89 $kWh/m^2/day$ and 3.88 $kWh/m^2/day$. Also, the irradiation varies depending on seasons. Usually, summer has the greatest irradiation.

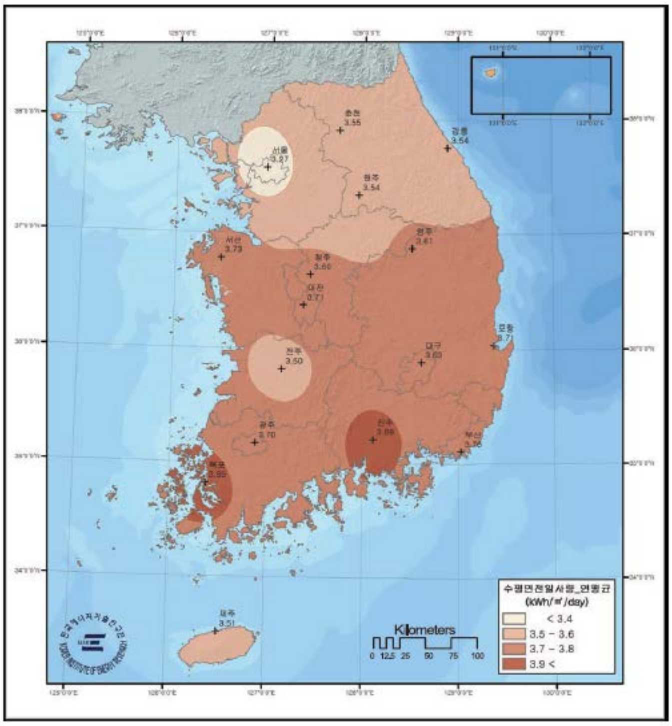

Figure 157. Global horizontal irradiation distribution map of Korea
* Source: Korea Renewable Energy Resource Atlas (2015: 9)

Relevant Size of PV Systems and Costs

Capacity factors of PV systems are in the range of 10.1% to 24.7% for fixed tilt systems in Asia, excluding Chana and India in 2016. The weighted average is 16.6% (REN21, 2016: 83). This paper assumes that a capacity factor of residential PV systems in Korea is 16.6%. By using this capacity factor, needed capacity of solar PV per household is 0.87 kW[11].

Total system levelized cost and levelized capital costs of a residential solar PV are respectively 0.09 USD/kWh and 0.07 USD/kWh (EIA, 2017). Each household needs 2,648.69 USD for total costs and 2,187.50 USD for capital costs. For the costs, it is assumed that solar panels generally have a 25-year life.

	Total system LCOE (USD/kWh)	Levelized capital costs (USD/kWh)	O&M costs (USD/kWh)
Solar PV	0.09	0.07	0.01

Table 10. Costs of residential solar PV systems
* Source: US Energy Information Administration, 2017
* LCOE: Estimated LCOE (simple average of regional values) for new generation resources, for plants entering service in 2022

4.3.2.2. Small-scale wind turbine

Figure 18. Small scale wind power

[11] $3.46\ \text{kWh} \div (0.166 \times 24) = 0.87$

* Source: NREL image gallery

Advantages and Disadvantages

Electricity from wind is generated by using turbines to convert the wind's kinetic energy into electrical energy. Like solar PV, wind also does not degrade environment and produce CO2 emissions. Strength of wind power is that it is modular so that increase in demand over time may be met by simply adding more modules (Brown et al, 2011: 6). In addition, wind power is matured technology, so that onshore wind is now one of the lowest-cost sources of electricity available (IRENA, 2014: 55). However, wind power is also an uncertain source of electricity. And birds and grassland species can be negatively affected by the wind power.

Wind power potential in Korea

Figure 20 shows average wind speed distribution in Korea. Wind power has more potential in coastal areas and islands rather than inland areas. In particular, among coastal areas and islands, south areas have higher wind speed. And in Gangwon-do with high mountains has high wind speed.

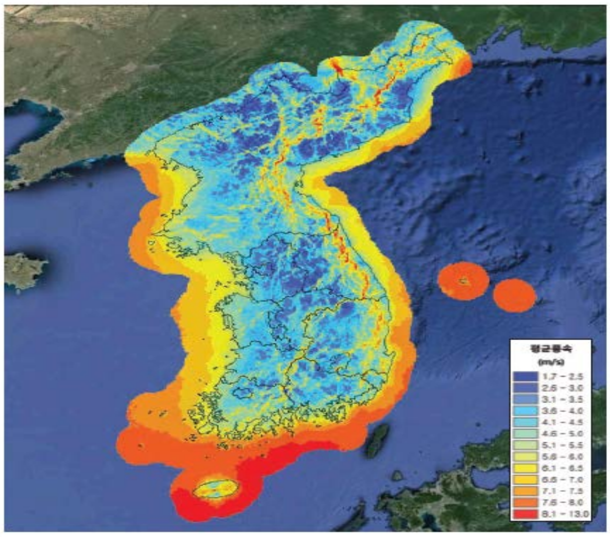

Figure 169. Average wind speed distribution in Korea

* Source: Korea Renewable Energy Resource Atlas (2015: 21)

Relevant Size of Wind Power and Costs

Capacity factors of onshore wind power are in the range of 17.2% to 43.5% in Asia, excluding Chana and India in 2016. The weighted average is 24.3% (REN21, 2016: 85). This paper assumes that a capacity factor of small-scale wind power in Korea is 24.3%. By using this capacity factor, needed capacity of solar PV per household is 0.59kW.

Total system levelized cost and levelized capital costs of wind power are, respectively, 0.16 USD/kWh and 0.13 USD/kWh (EIA, 2017). Each household needs 4,904.74 USD for total costs and 4,144.41 USD for capital costs. For the costs, the lifetime of wind power is assumed as 20 years.

	Total system LCOE (USD/kWh)	Levelized capital costs (USD/kWh)	O&M costs (USD/kWh)
Land-based Wind	0.16	0.13	0.02

Table 11.Costs of wind power

* Source: US Energy Information Administration, 2017

* LCOE: Estimated LCOE (simple average of regional values) for new generation resources, for plants entering service in 2022

4.3.2.3. Solar thermal heater

Figure 20. Solar thermal water heater, * Source: US department of energy

Advantages and Disadvantages

This is a direct solution influencing on heating energy expenditures. Solar thermal can be used for air-heating and water-heating through absorption, storage, and thermocycling of solar thermal. Compared to solar PV, a solar thermal heater has higher efficiency. Even though this system also has instability like solar PV, existing boilers can be combined with a solar thermal heating system so that additional burden resulted from the instability can be ignored.

However, an important weakness is that this system is likely to be destroyed. Periodic inspection is needed for the system. In particular, a solar thermal water heater uses water to store the solar thermal. Water weighs a lot, it expands when it freezes, and it can cause scaling damage to pipes when it boils (Slater, 2013). In this vein, in winter when necessity of the system is increased, significant thermal losses from water tank and solar thermal collectors are inevitable. Also, scaling of mineral deposit within the storage and pipelines should be needed when domestic water has minerals.

Relevant Size of Solar Thermal Heater and Costs

Costs are usually depending on the collector's size. And the collector area is defined as follows: $\frac{\text{required energy}}{\text{efficiency}*\text{limiting irradiation}}$. When required energy, limiting irradiation, and system's efficiency[12] are assumed as 3.46kWh, 3.7 kWh/m^2/day, and 48%, collector's size is determined as 1.95 m^2. This is much smaller than a common size of solar thermal heating system of 5~10m^2. And, life time of the system is assumed as 15 years. Based on the above assumption, total costs and installation costs of the solar thermal system are, respectively, 2,273 USD and 1,832 ~ 2,382 USD.

	LCOE (USD/kWh)	Installation costs (USD/m$^2_{gross}$)
Solar thermal	0.17 ~ 0.21	943.05 ~ 1,222.47

Table 12. Costs of solar thermal heating system
* Source: Global Solar Thermal Energy Council

4.3.2.4. Comparison with the LPG project

The above renewable energies seem to be much cheaper alternatives rather than the LPG project. In the case of Samgok-ri, Chungbuk, the initial installation cost of the LPG project is about $0.3 million USD per village with 69 households. The initial installation costs per each household are 4,347 USD. By using household survey in 2016, it can be assumed that the LPG project can reduce energy expenditures of 5,026[13] won per household. That is, the benefits per household of the LPG project

[12] The efficiency of a solar collector depends not only on its materials and design but also on its size, orientation, tilt, and temperature. The efficiency, 48%, is assumed according to Rome in Italy (in a lecture note of Lughi in University of Trieste, Italy.)

[13] By using retail prices and caloric values of LPG in cylinder and kerosene, the below table can be

are lower than that of renewable energies, which is 12,623 won. However, installation costs are higher than renewable energies, when fossil fuels are considered, the LCOE can be much higher than that of renewable energies.

This estimation is opposite of common knowledge regarding renewable energies. However, there is an important difference causing the result between the renewable energy options and the LPG project. Renewable energy options are assumed as adjuvant facilities to existing energy facilities, whereas the LPG project is a complete substitution of existing energy facilities. For this reason, costs of the LPG project can be higher than renewable energies even though the project depends on relatively cheap fossil fuel.

4.3.2.5. Findings

The below three options are for reducing energy expenditures of 12,623 won per month per household. So, capacities of all three options are much smaller than

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calculated. Total caloric value of LPG in cylinder and kerosene in 2016 is 1,190,110 MJ. The amount of LPG with the same caloric value of 1,190,110 MJ is 23,613 kg (= 1,190,110/50.4). And expenditure for the amount of LPG in the LPG project is 19,575,421 won (=23,613 kg * 829 won/kg). Consequently, 8,598,633 won is reduced by the LPG project. Reduced expenditures per household is 5,026 won. (the number of household is 1,711)

	LPG in cylinder	Kerosene	total
Expenditures (won)	9,596,183	18,577,871	28,174,055
- retail price (won/kg, won/ℓ)	1,711	753.4	-
Consumption (kg, ℓ)	5,609 kg	24,659 ℓ	-
- Caloric value (MJ/kg, MJ/ ℓ)	50.4	36.8	-
Caloric value (MJ)	282,670	907,440	1,190,110

common residential-scale facilities, which makes effects on the results with relative low costs. Among the three options, the total cost of solar PV is the lowest, and the costs of wind power and solar thermal are similar. The relatively low costs of the solar thermal are attributed to its short lifetime. And, frequent repairs of solar thermal cause inconvenience to rural households, which aggravates the current inconvenience resulted from usage of LPG in a cylinder and kerosene. Consequently, solar PV or wind power should be selected for rural households. According to potentiality of renewable resources in each area, the capacities and costs can be changeable. So, uniformly deciding which one is better is difficult. In terms of LCOE, solar PV has an advantage, and, solar PV on rooftop is a much more familiar form than residential wind power in Korea. In addition, installation costs as initial costs can be supported by Korean government more easily than O&M costs. So, rural households can prefer solar PV than wind power.

	capacity	Total costs (USD)	Capital costs(USD)	O&M costs (USD)
Solar PV	0.87 kW	2,648.69	2,187.5	327.19
Land-based wind	0.59 kW	4,904.74	4,144.41	610.76
Solar thermal	1.95 m2	1,832 ~ 2,383	2,273	N.A.

Table 13. Capacity and costs of each renewable energies

* Assumptions: Lifetimes for costs is assumed, respectively, as 25 years, 20 years, and 15 years.

4.3.3. Policies for renewable energies

In this chapter, how to deploy more renewable energies in rural areas is researched. For this, existing policies for renewable energies should be researched. Especially, policies in the US and Germany are compared to policies in Korea.

4.3.3.1. Current policies in Korea

A renewable energy goal of Korean government was to supply 11.0% of total primary energy supply and 13.4% of total electricity with renewables by 2035(2014, Korea's the 4th national basic plan for new and renewable energies). For this goal, diverse policy scheme is applied: renewable portfolio standard (RPS), financial support, mandatory for public organization to set renewable facilities, renewable fuel standard and so on.

However, after the new government was formed in 2017, it announced a new goal for renewable energies. The new goal is to supply 20% of total electricity with renewable energies by 2030. For the aggressive goal, Korean government is setting new policies and revising current policies like temporary introduction of Feed in Tariff, simplification of authorization processes and so on.

Policy	Description	Amount
RPS	Targets for renewable energy in total electricity supply mix at the national or state/provincial levels	2015: 3.0% -> 2024: 10.0%
Loan	Low-interest loan for investment or operation cost.	Investment: up to 10 billion won Operation cost: up to 1 billion won
Tax credit	Deducting a part of investment for renewable energies from income tax or corporate tax	1~6% Expiration: Dec. 2018
mandatory for public organizations to set renewable facilities	Public organization should set renewable energy facilities in their buildings.	2014: 12.0% -> 2020: 30.0%

renewable fuel standard	Obligation to blend biodiesel to fuel in transportation sector	2015: 2.5% -> 2018: 3%

Table 14. Renewable energy policies in Korea
* Source: Korea 4th National Basic Plan for New and Renewable Energies, Ministry of Trade, Industry and Energy, 2014

4.3.3.2. Policies in other countries

The US federal policies for deployment of renewable energies are Production Tax Credit (PTC), Investment Tax Credit (ITC) and Modified Accelerated Cost Recovery System Depreciation Schedule (MACRS). State policies for deployment of renewable energies are RPS, Net Metering, state tax credit, property tax exemptions, state sales tax exemptions, grants, clean energy financing program, subsidized loans and so on.

Policy	Description	Amount / expiration
PTC	A per-kilowatt-hour tax credit for electricity generated by qualified energy resources and sold by the taxpayer	(Systems Commencing construction after December 31, 2016) wind: $0.0184/kWh for first 10 years of operation, All other technologies: not eligible (Systems Commencing construction prior to January 1, 2017) wind, geothermal, closed-loop biomass, and solar systems not claiming the ITC: $0.023/kWh, Other eligible technologies: $0.012/kWh, Applies to first 10 years of operation Wind: ~ Dec. 31, 2019, Others: ~ Dec. 31, 2016
ITC	Allows the tax credit to be taken based on the amount invested rather than electricity produced.	30% for solar, fuel cells, wind, 10% for geothermal, microturbines and CHP. the expiration date for solar technologies and PTC-eligible technologies was extended, with a gradual step down of the credits between 2019 and 2022.

MACRS	Five year accelerated depreciation schedule means greater “loss” on paper, reduces taxes	depend on tax situation No expiration

Table 15. Renewable energy policies in the US
* Source: NREL, 2015, Renewable Energy Policies and Industries

In the case of Germany, in the National Action Plan, the federal government estimates the share of renewable energies in gross final energy consumption to be 19.6% in 2020. The share of renewable energies in the electricity sector will therefore amount to 38.6%, the share in the heating/cooling sector will be 15.5%, while in the transport sector it will be 13.2%.

Policy	Description	Amount
Feed-in tariff	For power plants up 100 kW the support system is based on a feed-in tariff, which the grid operator pays to the plant operators.	The amount of tariff is set by law and is usually paid over a period of 20 years.
KfW RE Program–Standard	Low-interest loans with a fixed interest period of 10 years including a repayment-free start-up period for investments in installations for electricity production. For all technologies	Up to 100% of the investment costs eligible for financing (without VAT), however, not more than EUR 50 million per project.
KfW Program offshore wind energy	Loans and financing packages to support companies wanting to invest in offshore wind farms in the German Exclusive Economic Zone or in 12 nautical-mile zone of the North and Baltic Sea.	up to 50 /70 percent of overall external capital requirements, max. EUR 400 / 700 million per project
KfW Consortium Loan Energy&Environment Program	Consortium loan between up to EUR 4 billion for on-shore wind farms and photo-voltaic installations	The risk assumption can cover a maximum of 50% of the entire consortium financing.
KfW RE Program Premium	Low interest loans and grant repayment support for electricity generation in deep geothermal installations.	Loans for deep geothermal installations are granted up to 80% of the eligible investment costs.

KfW RE Program “Storage”	Supports the usage of stationary battery storage systems, related to a PV installation, which is connected to the electricity grid.	Up to 100% of the net investment value is eligible for financing.
Market premium	Plant operators of RES plants exceeding an installed capacity of 100 kW which are not obliged to take part in the tendering procedures are supported by a market premium for electricity they sell directly.	The amount of the market premium shall be calculated each month.
Tendering	Onshore and offshore wind projects starting from 750 kW, solar projects starting from 750 kW biomass plants starting from 150 kW and already existing biomass plants must be awarded in a tendering procedure. The tendering procedure will also set the level of this support.	
Flexibility surcharge	The operators of new biogas plants may claim additional support for providing capacity for on-demand use.	The amount of the flexibility surcharge is 40 EUR per installed kilowatt per year for as long as the biogas plant is eligible for the auctioned market premium or the feed-in tariff
Flexibility premium	The operators of biogas plants that have been commissioned before 1.8.2014 may claim additional support for providing additionally installed capacity for on-demand use.	The amount of the flexibility premium is 130 EUR per additionally installed kilowatt per year for 10 years

Table 16. Renewable energy policies in Germany

* Source: OpenEI developed by National Renewable Energy Laboratory (NREL)

4.3.4. Findings

Compared to Korea, Germany has more aggressive policies for deployment of renewable energies. The difference of the initiatives on renewable energies is one of the reasons for the gap in the share of national energy need served by renewable energies. The portion of renewable energies in total electricity supply in 2016 is 7% in Korea, 29.3% in Germany, and 14.9% in the US (Renewable Energy 3020 Plan, 2017). However, just making policies aggressive cannot be a solution for wide deployment of renewable energies. Social acceptance and interests for renewable energies are also needed. Tomei and Gent (2005: 14) insist that the priorities of electricity systems are to match people's priorities. Failing to do this may lead to irregularities that could result not only in negative consequences for people, but for the electricity systems too. Saghir (2005; 10) also argues that energy reforms designed and implemented without local involvement can end up hurting rather than benefiting the poor. So, it is necessary to design renewable energy policies accorded with priorities of local communities, especially for rural households, and encourage their acceptance for renewable energies

5. Conclusion

Rural households bear heavy burden compared to those in urban areas. Disparities in natural gas pipelines distribution is the main cause of this problem. For instance, because of the uneven distribution of natural gas pipelines, rural households have been forced to use expensive LPG supplied in a cylinder and kerosene, whereas urban households can use cheap natural gas for cooking and heating. While Korean government has implemented a LPG storage tank project in small rural villages to alleviate this inequity in energy supplies between urban and rural households, the situation remains acute requiring additional policies for rural households. The LPG project is a welcome cost-effective solution that would reduce inconvenience arising from usage of LPG in a cylinder and kerosene, and improves safety in energy usage at the local level. However, this project increases dependency on fossil fuels by rural households and potential long-term lock-in in expensive high-carbon energy sources which does not comply with the current policy of accelerating investment in renewable energy and distributed generation in Korea.

This study shows that the potential of energy voucher program in helping to mitigate against the growing energy inequity in rural settings. Also, as a more-environmentally-friendly and long-term policy tool, this study recommends increased adoption of renewable energy and decentralized generation technologies such as solar PV and residential wind power. To accelerate investments in these low-carbon technologies, the paper also recommends adoption of policies, finance, and socio-economic instruments that encourage deployment of renewable energies as well as encourage social acceptance of these technologies in rural parts of the country.

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