Regional Energy Demand Analysis Using Household CO2 Statistics: Implications of the Carbon Pricing Policy in Japan

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To maximize the effectiveness of carbon pricing and minimize its burden, it is critical to understand Japan's energy demand characteristics accurately. Therefore, this study focuses on analyzing the regional energy demand of the household sector using the Ministry of the Environment's Household CO2 Statistics. It uncovers significant regional variations in energy consumption, shaped by climate, socioeconomic factors, and infrastructure. The investigation into utility costs and the tax burden reveals regional disparities and a regressive effect on lower-income households and rural regions, implying that imposing a uniform carbon pricing system is not feasible. Instead, a system design tailored to specific circumstances is required.

Additionally, the study looks at international cases from the US, UK, and France, highlighting the challenges they faced in introducing energy and carbon taxation, including experiences of public backlash.

In conclusion, the analysis underscores the need for clear and detailed communication about policy impacts to build public support and ensure equitable and effective policies for climate change.
Keywords: Carbon pricing, Energy Price, Household Energy, Regional disparity, Tax Burden

I. Introduction

In May 2023, Japan enacted the "Act on Promoting a Smooth Transition to a Decarbonized Economic Structure (GX Promotion Act)." The act is designed to facilitate the development and implementation of innovative decarbonization technologies aimed at achieving Japan's 2050 carbon neutrality target. The primary mechanism established under this act involves the issuance of "Climate Transition Bonds" totaling 20 trillion yen over the next decade, starting from FY2023. These bonds are used as a financial resource for technologies and policies that contribute to the transition to carbon neutrality.

To ensure the financial viability of these bonds, the next three programs, collectively referred to as "the Growth-Oriented-Carbon Pricing," are slated to be implemented as tools for collecting financial resources. These programs are a voluntary emissions trading scheme from FY2026, a fossil fuel surcharge on fossil fuel importers from FY2028, and a specific surcharge on electricity producers related to emissions allowances from FY2033.

Understanding the intricate impact of carbon pricing on an economy necessitates assessing the anticipated reduction impacts and costs within the context of a society's energy demand

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characteristics and socio-economic backgrounds. For instance, in the residential sector, the effects and cost burdens of carbon pricing are influenced by a myriad of factors including household income, dwelling types, availability of alternative energy sources, regional climates, and advancements in energy efficiency technologies.

In ~~the~~ microeconomics theory, the impact of price changes on consumption can generally be categorized into income effects and substitution effects. Typically, households with higher incomes or access to a variety of energy alternatives tend to exhibit stronger substitution effects, whereas lower-income households or those with limited alternatives experience more pronounced income effects. Hence, a thorough understanding of the characteristics of targeted energy demand sectors is essential for maximizing the effectiveness of the carbon pricing.

Therefore, this paper analyzed the energy demand characteristics of Japan's residential sector, which is indispensable as basic information for policy consideration, using the Ministry of the Environment's "Statistical Survey of CO2 Emissions from the Household Sector (Household CO2 Statistics)". Given the susceptibility of residential energy demand to climatic influences compared to other sectors, this analysis attempted to identify regional energy demand trends based on a classification system as outlined in Table 1.

The analysis revealed that there were significant differences in energy demand, utility costs, and tax burdens in the residential sector across regions. This implied that the impact of the introduction of carbon pricing depends on socioeconomic conditions, such as regional climate, population characteristics, and infrastructure development, and that it was difficult to apply a uniform policy. In particular, the burden of utility costs on households was particularly heavy in rural areas and among households with low incomes, highlighting the problem of regressivity.

Table 1. Regional Classification in Japan Used for the Analysis

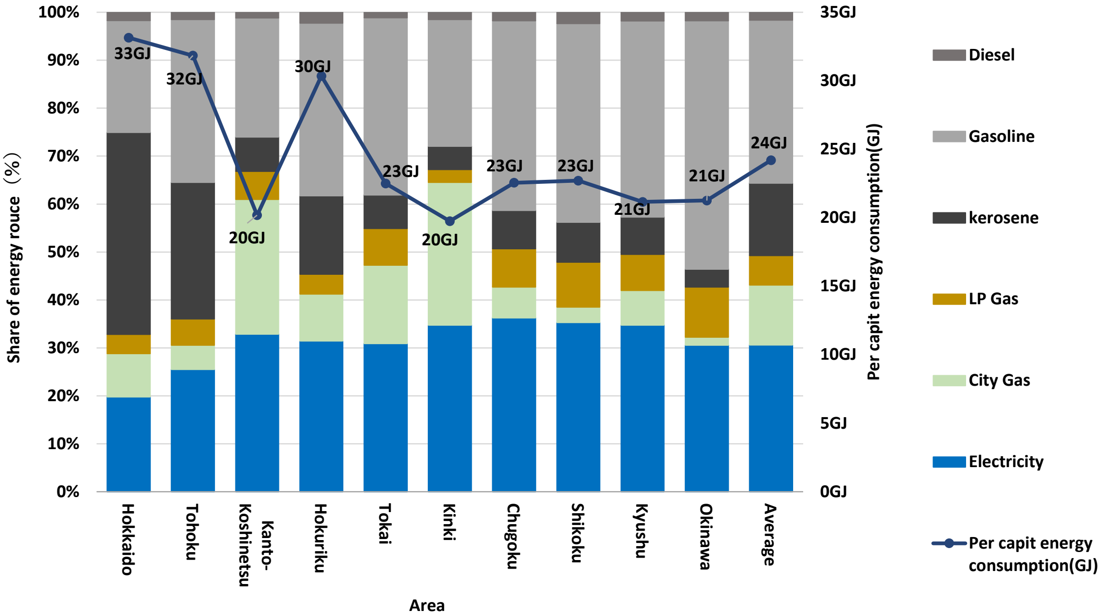
Regional Classification	Prefectures
Hokkaido	Hokkaido
Tohoku	Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima
Kanto-Koshinetsu	Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Yamanashi, Nagano
Hokuriku	Niigata, Toyama, Ishikawa, Fukui
Tokai	Gifu, Shizuoka, Aichi, Mie
Kinki	Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama
Chugoku	Tottori, Shimane, Okayama, Hiroshima, Yamaguchi
Shikoku	Tokushima, Kagawa, Ehime, Kochi
Kyushu	Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima
Okinawa	Okinawa

2. Regional Characteristics of Energy Demand and Utility Costs

2.1 Regional Per Capita Demand by Energy Source

Figure 1 illustrates the per capita energy consumption and the proportion of fuels used in the residential sector by region. The Hokkaido, Tohoku, and Hokuriku regions show significantly higher per capita energy consumption, which is primarily due to heating needs in winter. In particular, the use of kerosene is remarkably high. Conversely, in the southwestern regions, such as Okinawa, Kyushu, Shikoku, and Chugoku, heating demand in winter is relatively low, but the demand for automotive gasoline is prominent.

Figure 1: Regional Per Capita Total Energy Demand and Proportion by Energy Source (2020)



Source: Based on the Ministry of the Environment's "Household CO2 Statistics"

Furthermore, in major urban areas, including Kanto-Koshinetsu, Kinki, and Tokai regions, per capita energy consumption is lower, with a higher usage ratio of electricity and city gas. This phenomenon is influenced by the characteristics of urban areas: high public transport infrastructure and smaller residential floor areas. In addition, the proportion of the working population is higher in urban areas,(2) resulting in shorter time spent at home. However, recent promotions of telework may have reduced these differences.(3) Such changes in social circumstances are considered to be new factors affecting household energy demand. In conclusion, it was revealed that household energy demand varies based on the region.

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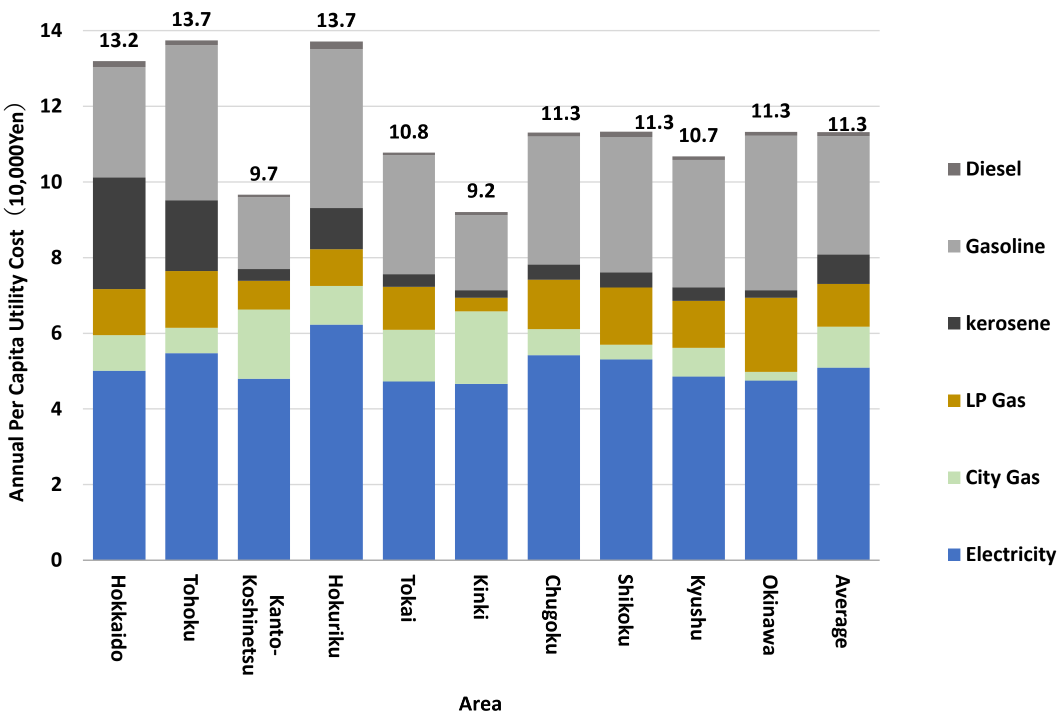
2.2 Utility Costs

Figure 2 presents regional characteristics of per capita utility costs in the residential sector. Per capita utility costs are significantly higher in colder regions, such as Tohoku, Hokuriku, and Hokkaido, compared to other regions, due to the greater heating demand as previously mentioned. For example, according to the statistics on heating degree days and cooling degree days,[4] Sapporo, in the colder region, has 2.4 times the national average of heating degree days, whereas Fukuoka, in a warmer climate, remains at 1.4 times the national average for cooling degree days. On the other hand, Kinki, Kanto-Koshinetsu, and Tokai regions exhibit the lowest level of utility costs. As shown in 2.1, these regions, which include large urban areas, feature a relatively warm climate, well-established city gas networks, compact housing, less home time, and a comprehensive public transportation network, resulting in lower energy demands. These factors combine to make the per capita utility costs in these metropolitan areas the lowest among all regions.

Figure 2: Annual Per Capita Utility Cost in the Residential Sector (2020)



Source: Based on the Ministry of the Environment's "Household CO2 Statistics"

2.3 Level of Utility Cost Burden

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In addition to the level of utility costs, the ratio of utility costs to income is an important indicator in assessing the level of burden to each household. A higher ratio of utility costs to income implies that less financial capacity is left for other consumer purchases. Figure 3 arranges the regions by the average per capita income and shows the ratio of utility costs (electricity, city gas, LPG, kerosene, gasoline, diesel) to income. Note that the average per capita income is calculated by dividing the average household annual income by the number of household members, including non-working members, such as the elderly and children, hence it is typically lower than the general per capita annual income statistics.

In terms of per capita income levels, Kanto-Koshinetsu ranks the highest, followed by other metropolitan areas, such as Tokai and Kinki. Conversely, Okinawa has the lowest per capita income, followed by southwestern regions outside of Honshu, such as Shikoku and Kyushu. In contrast, the proportion of utility costs relative to per capita income (utility cost burden rate) exhibits an opposite trend, being lower in Kanto-Koshinetsu, Kinki, and Tokai, and higher in Okinawa, Tohoku, Hokuriku, and Hokkaido. A relatively strong negative correlation is observed between per capita income and the utility cost burden rate, indicating that regions with lower incomes tend to have higher utility cost burdens.

Figure 3: Regional Per Capita Income and the Ratio of Utility Costs to Income (2020)

Source: Based on the Ministry of the Environment's "Household CO2 Statistics"

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3. Energy-Related Taxes

To what extent do taxes and surcharges constitute the utility costs paid by households? In fact, when purchasing energy, consumer focus tends to be on the final price, with little awareness of the specific amount of taxes paid on electricity and gas used at home or gasoline and diesel purchased at gas stations. While the per liter price of gasoline at gas stations is considered important, the amount of tax embedded in the price is not a major concern. Even in cases where the renewable FIT surcharge is explicitly charged to the electricity price, only a few consumers are aware of it. For instance, a survey conducted in August 2022(5) found that only 19% of respondents understood the meaning of the renewable energy surcharge. The breakdown of this 19% is as follows: 8% understood and were dissatisfied, and 11% understood and had no particular dissatisfaction.

On the other hand, an understanding of the current state of taxes and surcharges related to energy is essential for the concrete design of carbon pricing schemes. This is because, in addition to the current burden on consumers, a carbon price will be imposed. Therefore, when introducing a new system, it is crucial to thoroughly understand the existing burden and carefully consider the design of the system. Consequently, this section analyzes the types of taxes and surcharges imposed on household energy demand and the burden they place on consumers.

3.1 Overview of Energy-Related Taxes

A variety of taxes and surcharges on energy use are already imposed under the current tax system. The total amount collected in fiscal year 2022 includes approximately 2.7 trillion yen from the Renewable Energy Feed in Tariff Surcharge (hereafter referred to as FIT surcharge), followed by about 2 trillion yen from the gasoline tax. However, the FIT surcharge unit price was significantly reduced from 3.45 yen/kWh in fiscal year 2022 to 1.40 yen/kWh in fiscal year 2023, leading to an expected temporary decrease in collection amount to 1.1 trillion yen for that year, a reduction of 60%. This decrease in FIT surcharge price is attributed to the rise in avoidable costs due to Russia's invasion of Ukraine, indicating that electricity prices, including those derived from renewable energy, have risen more than expected. On the other hand, the FIT surcharge rate in 2024 reached a record high of 3.49 yen/kWh. This is attributed to the stabilization of fossil fuel procurement costs, which resulted in a decline in market electricity prices.

Taxpayer coverage varies by fuel type, and there is considerable debate over how much of the energy price can be passed on to the final consumer, but generally, a certain degree of tax burden is shifted to consumers.(6) As a result, the types of taxes and surcharges borne by households include the petroleum and coal tax, gasoline tax, light oil delivery tax, electric power development promotion tax, and renewable FIT surcharge. In the following section, these taxes and surcharges are collectively referred to as "taxes" for simplicity.

Table 2 Energy-Related Taxes and Revenue (in billion yen) for FY 2022

Item	Taxable Object	Taxpayer	Tax Rate	FY 2022 Revenue (billion yen)	Notes
Gasoline Tax	Gasoline	Manufacturers and importers from bonded areas	48,600 yen/kL (Basic tax rate: 24,300 yen/kL)	2,079	General revenue for the national government
Local Gasoline Tax	Gasoline	Manufacturers and importers from bonded areas	5,200 yen/kL (Basic tax rate: 4,400 yen/kL)	223	Entire amount allocated as general revenue for local governments (of which 222.5 billion yen is allocated to local governments)
LPG Tax	Auto LPG	Fillers and importers from bonded areas	17.5 yen/kg	10 (of which 5 billion yen is allocated to local governments)	Half of the tax revenue is allocated as general revenue for local governments
Petroleum and Coal Tax	Crude oil, petroleum products, natural gas, LPG, coal, etc.	Manufacturers, importers from bonded areas, miners	- Crude oil, petroleum products: 2,800 yen/kL (Basic tax rate: 2,040 yen/kL) - Natural gas, LPG: 1,860 yen/t - Coal: 1,370 yen/t	660	Revenue used for ensuring stable fuel supply and advancing energy supply-demand structure (Including 289 yen/t-CO2 for global warming countermeasures tax) (Basic tax rate: 1,080 yen/t) (Basic tax rate: 700 yen/t)
Aviation Fuel Tax	Aviation fuel	Aircraft owners	13,000 yen/kL (Basic tax rate: 26,000 yen/kL)	49	Revenue used for airport development and local airport countermeasures (of which 15.2 billion yen is allocated to local airport countermeasures; 4/13 of tax revenue)
Electric Power Development Promotion Tax	Electricity sold by general power transmission and distribution businesses	General power transmission and distribution businesses	375 yen/1,000 kWh	313	Revenue used for power source location measures, power use measures, and nuclear safety regulation
Light Oil Delivery Tax	Light oil	Persons taking delivery of light oil from special contractors or primary wholesalers (e.g., gas station	32,100 yen/kL (Basic tax rate: 15,000 yen/kL)	931	General revenue for local governments (Partially allocated to designated cities)
Renewable Energy FIT Surcharge	Electricity sold by general power transmission and distribution businesses	Retail electricity suppliers	3.45 yen/kWh (FY 2023: 11,133)	2,744	Used to cover part of the costs for electric companies to purchase renewable energy at a fixed price and period

Source: Compiled from materials from the Ministry of Finance, Ministry of Economy, Trade and Industry, and Ministry of the Environment.

3.2 Regional Tax Burden Estimation

Various taxes are imposed at different stages until energy is supplied to the final consumer, but what is the actual burden for final energy demand? To grasp the actual burden on households, it is necessary to understand the input fuels. For example, the petroleum and coal tax is imposed at the stage when crude oil and liquefied natural gas, which are raw materials for energy products, are imported or produced. These fuels are then converted to electricity in the power generation process and supplied to the final consumer through transmission lines if they are electric. Some of these fuels are also converted to city gas in the city gas manufacturing process and supplied through pipelines. With regard to crude oil, it is input into atmospheric distillation units and then converted

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to various petroleum products. Therefore, to accurately assess the actual amount of the petroleum and coal tax paid by households, it is essential to understand the quantity of fuel input in the energy conversion process. Addressing this aspect of the petroleum and coal tax, the per capita fuel input should be estimated. In this analysis, the final energy demand in "Region a" is used, along with supply losses (including power generation loss, in-house loss, transmission loss, gas product manufacturing loss, and petroleum product manufacturing loss), to estimate the per capita fuel inputs. For power generation, the input fuel amount （I_{ELa}） is calculated using formula (1). The gas product refining input fuel amount(I_{GSa}) is calculated using formula (2), and the petroleum product refining input fuel amount(I_{PPa}) is calculated using formula (3).

$$I_{ELa} = \sum_i^n \left(D_{ELa} S_{ELai} \Big/ \frac{TE_i \, TE_{EP}}{TE_{GP}} \right) \cdots\cdots\cdots(1)$$

$$I_{GSa} = D_{GSa} \; RE_{GS} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

$$I_{PPa} = D_{PPa} \; RE_{PP} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(3)$$

Per capita energy demand in “Region a” is set as per capita power demand (D_{ELa}), per capita gas product demand (D_{GSa}), and per capita petroleum product demand (D_{PPa}). The proportion of fuel input “i” in the power source composition (S_{ELai}), the power generation efficiency of fuel “i” (TE_i), the overall power generation terminal efficiency (TE_{EP}), the overall receiving terminal efficiency (TE_{GP}), the gas product refining efficiency (RE_{GS}), and the petroleum product refining efficiency (RE_{PP}) are defined. The overall power generation terminal efficiency, overall receiving terminal efficiency, and refining loss rate are referenced from the Comprehensive Energy Statistics.(7) The power generation efficiency of various fuels is sourced from the Comprehensive Resource Energy Study Group Power Generation Cost Verification Working Group 2021 material.(8)

On the other hand, gasoline tax, light oil delivery tax, power source development promotion tax, and renewable FIT surcharge are calculated based on the sales volume to final demand, so the payment amount is estimated by multiplying the final energy demand amount by the tax rate/surcharge unit price. Additionally, tariffs at the fuel import stage and consumption tax at the final consumption stage are imposed, forming components of the overall tax burden on energy use.

Further, consumption tax is also imposed on the petroleum and coal tax and gasoline tax (so-called “Tax on Tax"). However, tariffs and consumption tax, which are not specifically taxed on energy demand and are commonly imposed on other consumer goods, are excluded from this analysis.

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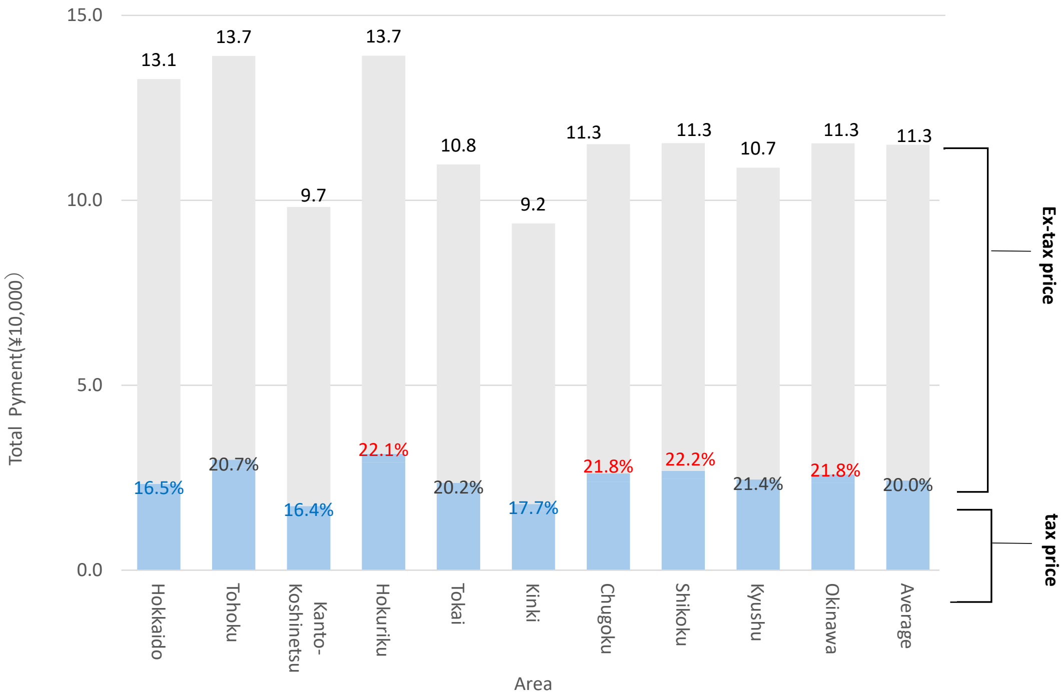
According to Figure 4, the region with the highest proportion of energy taxes in per capita utility costs in the residential sector is Shikoku, followed by Hokuriku, Okinawa, and Chugoku. On the other hand, Kanto-Koshinetsu, Hokkaido, and Kinki have the lowest proportions.

Figure 4: Per Capita Utility Costs and Tax Proportion in the Residential Sector (Annual, 2020)



Source: Estimated from the Ministry of the Environment's Household CO2 Statistics, Comprehensive Energy Statistics, and electricity business data, etc.

Figure 5 shows a detailed breakdown of taxes and the per capita tax payment amount. Looking at the tax payment amounts, Hokuriku and Tohoku significantly exceed other regions, while Kanto-Koshinetsu and Kinki are at the lowest level. Hokkaido, one of the regions with the largest per capita energy consumption, has a relatively low tax payment amount, as the tax burden on kerosene is lower compared to the gasoline tax and FIT surcharge. In Okinawa, Kyushu, Shikoku, and Chugoku, despite the average level of per capita energy consumption (Figure 1), the tax amounts are higher than the average. This is due to regional characteristics where the proportion of gasoline demand, which is subject to a higher gasoline tax rate, is larger.

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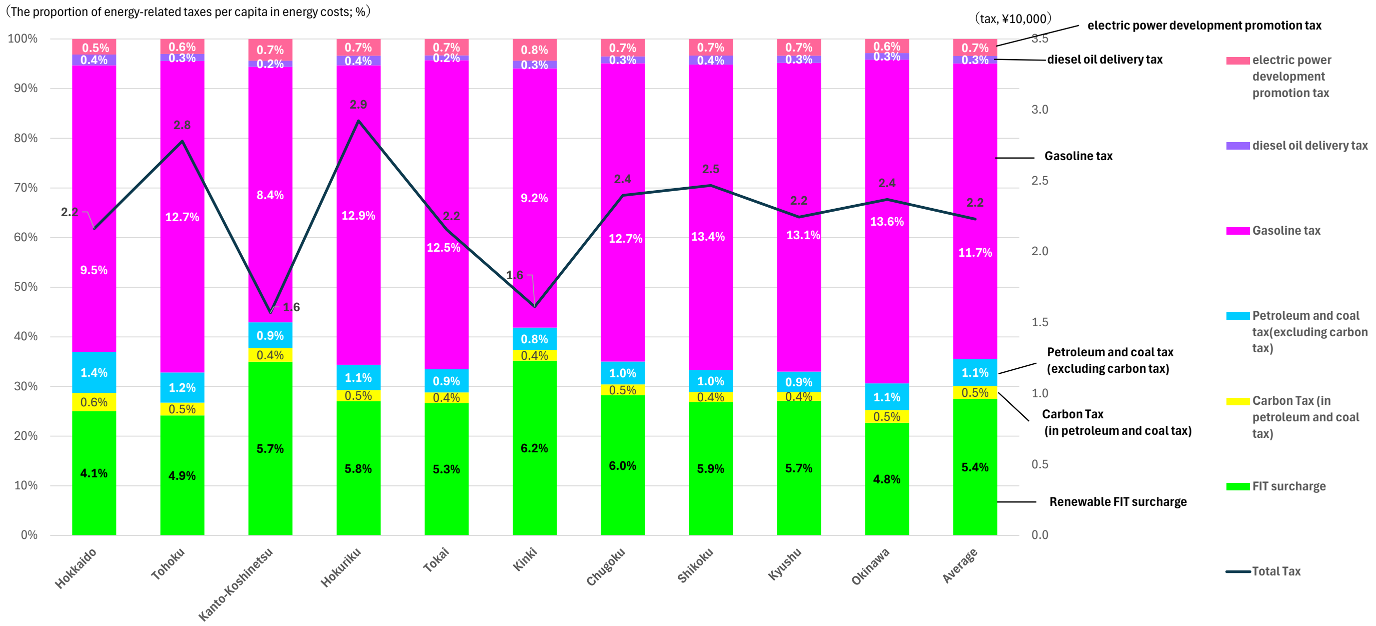
Figure 5: Proportion of Taxes and Surcharges on Household Energy Demand (Annual, 2020)



Source: Estimated from the Ministry of the Environment's Household CO2 Statistics, Comprehensive Energy Statistics, and industry data.

4. Overview of Energy Tax Burden Regional Differences

In this analysis, the regional characteristics of energy demand and utility costs in Japan's residential sector, and the per capita amounts of energy-related taxes based on estimates of primary input fuels were clarified by using the "Household CO2 Statistics." In addition, this analysis revealed that energy consumption patterns vary due to regional climate, population characteristics, and infrastructure conditions, and consequently, tax burdens also differ. Particularly, the analysis of the burden of utility costs on households indicated that households in rural areas or those with lower incomes tend to bear a heavier burden of utility costs, observing a 'regressivity' in utility costs. Therefore, it is suggested that the design of a carbon pricing system should take into consideration the specific regional characteristics of household energy demand.

Additionally, in light of the ongoing domestic discussions regarding the introduction of carbon pricing, the focus should shift to international examples. Specifically, examining the discussions surrounding the introduction of carbon pricing, identifying the major barriers, and analyzing consumer reactions can provide valuable insights and strategies for Japan to implement carbon pricing smoothly. Particularly, understanding the impact of rising energy prices on households and the social reactions

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to new tax burdens are crucial perspectives to consider in the design of Japan's carbon pricing policy.

5. Debate about the introduction of a carbon tax in major countries

In the United States, there have been several attempts to introduce energy taxes. However, as the impact of rising energy prices places a significant burden on households, especially in a car-dominated society, there has been historically strong opposition to increases in gasoline taxes and the introduction of a carbon tax. For example, in 1993, under the Democratic administration, the BTU tax (an energy tax) was nearly implemented. However, due to the strong regressive nature of the energy tax, public backlash, and industry lobbying, it was ultimately not introduced.[9] Reflecting this reality, the United States has refrained from implementing federal-level tax increases on energy. Consequently, gasoline prices and tax rates in the U.S. remain some of the lowest among major developed countries.[10] On the other hand, it is common in the United States for states to introduce individual policies. For example, a referendum was held in Washington State in 2016 that paired a reduction in sales tax with an introduction of a carbon tax. However, this referendum was defeated by a majority of 'no' votes. Furthermore, along with the midterm elections in November 2018, a revised proposal for a referendum that would allocate tax revenues to green subsidies was held, but it was again defeated by a majority of 'no' votes.[11][12] Washington State is one of the most politically liberal states in the United States, with a Democratic governor and a legislature dominated by Democrats. Furthermore, many residents understand the necessity of addressing climate change. However, even in such a favorable context, the failure to introduce a carbon tax underscores the significant emotional and political challenges associated with implementing a carbon tax in the United States.

In addition to the case of the United States, the experiences from European countries are also instructive. For example, in the United Kingdom, the Conservative Party, which was the ruling party in 1993, announced that it would impose a standard VAT rate (8% at the time) on gas and electricity for households, which had previously been zero-rated, in order to secure revenue. However, the public backlash was stronger than anticipated, leading to intense debates. Ultimately, the government addressed the issue by coupling the tax increase with enhanced energy-saving subsidies for low-income households. This experience influenced subsequent policy discussions on the Climate Change Levy, resulting in the exclusion of the household sector from the tax base. The UK's Climate Change Levy was initially designed to target the industrial sector, but strong opposition from industry led to a compromise involving a lower-than-planned tax rate and significant relief measures (as of 2023, reductions of 80-90% are available under certain conditions).(13)

In France, the "Yellow Vest Movement" emerged in November 2018 as a reaction to the proposed increase in the carbon tax, leading to multiple large-scale demonstrations in Paris. This protest garnered widespread support across France. Consequently, the Macron administration decided to freeze the planned carbon tax increase.(14) Notably, the "Yellow Vest Movement" became the longest-lasting protest in France since World War II.(15)

Examining the cases of major countries, it becomes evident that energy, like food and water, is a vital lifeline for both everyday life and industry, leading to significant opposition to new financial burdens. The impact of rising energy prices on households, particularly the disproportionate effects on lower-income groups—known as the issue of "regressivity"—makes taxation on energy a difficult policy to garner social support for. This opposition has sometimes resulted in political instability. Therefore, when implementing policies that would increase energy prices, it is crucial to thoroughly explain the necessity, benefits, and impacts of such policies to the public. Moreover, it is essential to consider measures that ensure fairness and to actively work towards gaining public understanding and support.

6. Conclusion and Policy Implications

This analysis aimed to provide fundamental information for a consideration of the introduction of carbon pricing, a new policy initiative. Using the "Household CO2 Statistics," the focus was on analyzing the regional characteristics of household energy demand and various energy-related taxes. Significant regional differences in household energy demand, utility costs, and tax burdens were revealed. These differences, influenced by local climate, demographic characteristics, and infrastructure development, suggest that a uniform application of carbon pricing policies is challenging. The burden of utility costs is particularly heavy on low-income households and rural areas, highlighting the regressive nature of such policies.

Furthermore, international case studies indicate that policies leading to increased energy prices carry risks of political turmoil and social resistance. The ongoing energy crisis has prompted the implementation of subsidy policies, akin to "reverse carbon pricing," in Japan and European countries to mitigate the impact on households. This situation underscores the need for cautious approaches to rising energy prices, even in regions actively pursuing climate change mitigation.

In the United Kingdom, Prime Minister Rishi Sunak acknowledged in a September 2023 speech(16) that the costs associated with the net-zero policy have been unnecessarily high and that there has been insufficient communication with the public regarding these costs. He emphasized that a future approach should prioritize realistic measures, cost transparency, and public consent.

In Japan, it is essential to conduct thorough examinations and provide careful explanations for any powerful policies that might increase energy costs or alter the way of life. Given these challenges, policymakers must first deeply understand the characteristics of household energy demand and the burdens faced by the public. Second, policymakers should ensure thorough and transparent communication about the necessity, benefits, and impacts of policies that would increase energy prices. Finally, they should consider and implement measures that address the fairness of such policies, particularly for vulnerable populations. This approach not only mitigates the regressive impact but also helps secure broader social acceptance and political stability when introducing carbon pricing.

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