The life cycle carbon emissions caused by households in Japan: current status and long-term perspectives

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Introduction

Global annual greenhouse gas (GHG) emissions have risen dramatically since the start of the industrial revolution and caused a series of adverse effects such as climate change. As the 26th Conference of the Parties to the United Nations Climate Change Framework Convention (COP26), a global summit that aims to fight against climate change, ended on November 13, 2021, most major emitting countries have announced their carbon reduction or carbon neutrality targets by mid-21st century. To achieve these targets, the carbon emissions from the household sector need our attention, as households can produce emissions directly through at-home activities like heating, cooking, and indirectly through upstream emissions associated with the production of consumption items, and consequently, the household sector accounts for a considerable proportion of the total carbon emissions. From 1982 to 2007, the energy consumption of the residential sector in Japan has doubled while the population has increased by only 10%[1]. Accordingly, the same trend of increase in carbon dioxide (CO_2) emissions caused by households has followed, where CO_2 emissions from the household sector in Japan have increased significantly since 1990[2]. Therefore, to achieve the nation's carbon neutrality by 2050, an ambitious target declared by Prime Minister Yoshihide Suga in October 2020[3], it is essential and urgent to manage household-induced carbon emissions.

For estimating household emissions, existing studies tend to consider different kinds of factors. Bastien Girod et al., build a model for changes in household greenhouse gas emissions due to higher income[4], and Underwood, A. J. tries to understand the role of demographic change in household carbon emissions using an EIO-LCA model[5]. Asumadu-Sarkodie, S. et al., argued that low carbon technology could help to reduce environmental pollution[6]. Büchs, M., et al., try to examine the impact of different socio-economic factors such as education, gender, etc. on household indirect and total emissions[7].

In most existing studies conducted in Japan, there is a lack of process-based inventory data of household commodities. Besides, 2050 scenarios for household emissions seem to be overlooked. Most importantly, few studies have addressed the quantitative impact of changes in consumer behavior on expenditure.

As the deadline for the reduction target of 2030 raised by the Japanese government looms, it becomes more and more important to understand current household carbon emissions and to examine the possibility of the attainment of Japan's 2030 reduction targets. Also, changes in lifestyles including consumer behavior are a prerequisite for sustaining reductions in GHG emissions and for bridging the emissions gap, thus it is necessary to quantify and understand the impact of these changes.

This study mainly aims 1) to estimate current household-induced CO_2 emissions by using process-based inventory data and to understand the impact of the COVID-19 pandemic based on the results; 2) to explore the possibility of the attainment of Japan's reduction targets in 2030 based on the results obtained by using 2030 inventory data; 3) to examine how will consumer behavioral changes affect future household carbon emissions in the distant future by setting different

expenditure scenarios in 2050.

Method and data

Life cycle accssement (LCA)

An initial approach to completing a life cycle assessment is a process-based LCA method. In a process-based LCA, one itemizes the inputs (materials and energy resources) and the outputs (emissions and wastes to the environment) for a given step in producing a product[7].

Inventory database for environmental analysis (IDEA)

IDEA is a database developed by JEMAI and AIST which mainly uses national statistics as its data source and aims to model the environmental impacts of all Japanese businesses comprehensively with a high resolution[10]. The inventory data is obtained through the method of process-based LCA.

The microeconomic data

The consumption data of households is obtained from the Family Income and Expenditure Survey (FIES) conducted every month by the Japanese government. The price data for each commodity is obtained from IDEA and the Retail Price Survey which is also conducted by the government.

The Framework for estimating and predicting household carbon emissions

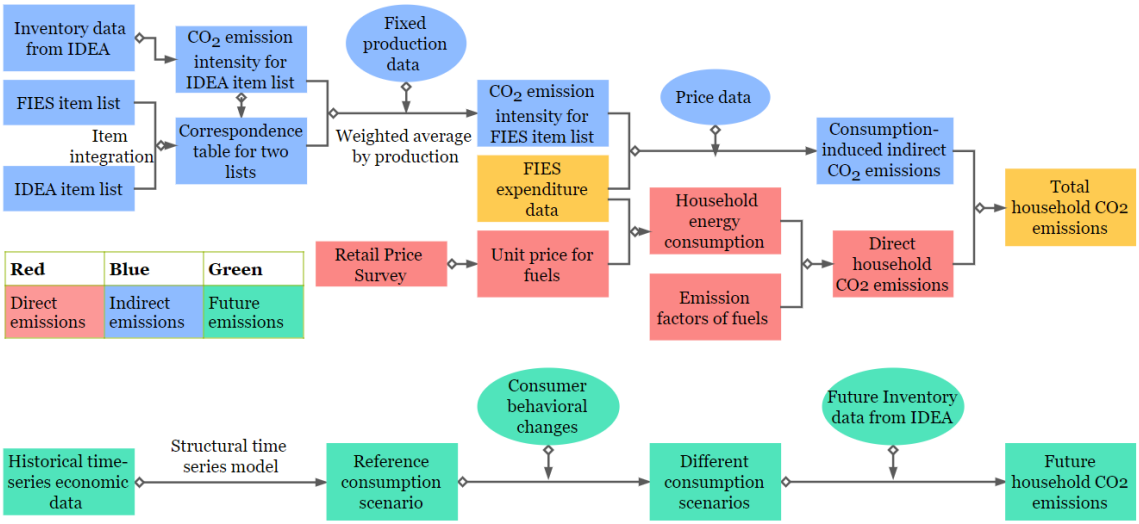

Fig. 1.Workflow for household CO_2 emissions estimation and prediction

Model for the prediction of future expenditure data

Structural Time Series Model （STSM） for expenditure prediction[8] is shown below.

$$exp_t = \mu_t + \lambda_t + \pi p_t + \tau y_t + v_t \qquad v_t \sim NID(0, \sigma_v^2) \qquad (1)$$

The reason for choosing STSM lies in that it allows for the examination of the relationship between expenditure, income and prices and a stochastic underlying trend and allows for stochastic seasonality so that, along with the stochastic trend, are included in the following long-run expenditure model[8].Compared to other time series models such as ARMA and ARIMA which only consider auto-regression and moving average, STSM is more comprehensive as it attempts quantify the contributions of the economic drivers (income and price) and Non-Economic Factors to determining household expenditure.

Future scenarios

See **Table 1.**

Result

For current household carbon emissions, the total household CO_2 emission including both direct and indirect emissions is approximately 10.977 t-CO_2 per household.

The consumption expenditures of different categories and induced CO_2 emissions in 2020 are shown in **Fig. 2**.

For future household expenditure and carbon emissions, the results are shown **Fig.3.**

Table 1

Assumptions in the three scenarios.

Expenditure	Food	Housing	Fuel, light & water charges	Furniture & household utensils	Clothing & footwear	Medical care	Transportation & communication	Education	Culture & recreation	Others
Reference Scenario given by model	-	-	-	-	-	-	-	-	-	-
Scenario A: Large Consumer behavior change	Animal-based: -75%; Plant-based: +50%	-	Electricty: +75%; Fuel: -90%	-50%	-50%	-	Personal vehicle use-related: -75%; Public transpotation-related: +50%	-	-	-
Scenario B: Small consumer behavior change	Animal-based: -50%; Plant-based: +25%	-	Electricty: +50%; Fuel: -60%	-25%	-25%	-	Personal vehicle use-related: -50%; Public transpotation-related: +25%	-	-	-
Behavioral change interpretation	A shift to plant-based diet and reduction of animal-based consumption (e.g. beef, pork, poultry, dairy and eggs	No changes	Penetration of net zero energy house (ZEH) and all-electric house: less expense on fuel and more on electricty;	Less expense on furniture due to environmental awareness	Less expenses due to environmental awareness	No changes	Less expense related to personal vehicle use due to car-sharing and a shift to public transportation	No changes	No changes	No changes
Note: all consumption changes are based on Reference Scenario										

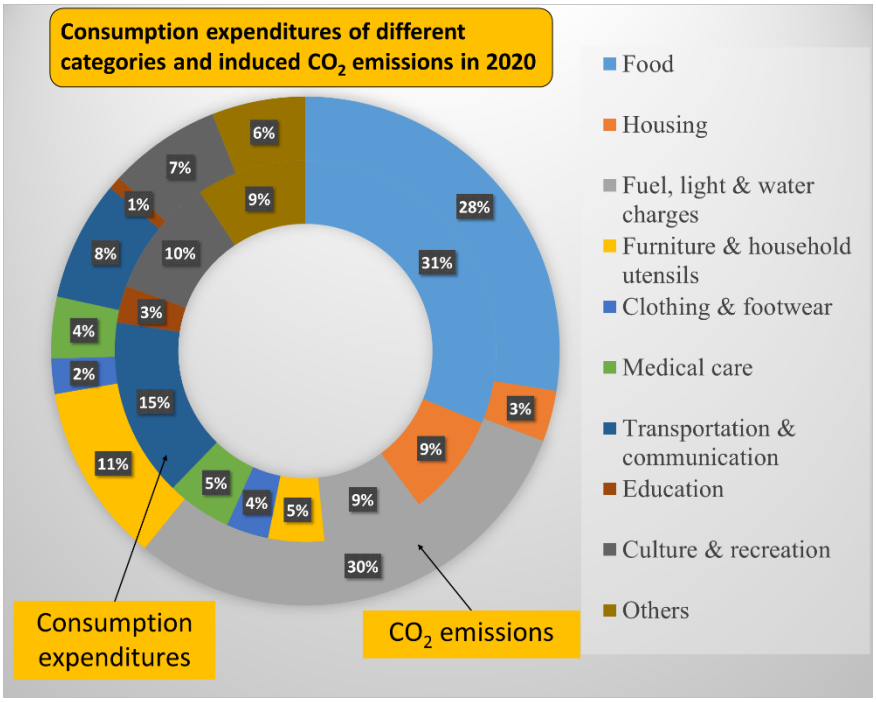

Fig.2. Consumption expenditures and induced CO_2 emissions per household in 2020

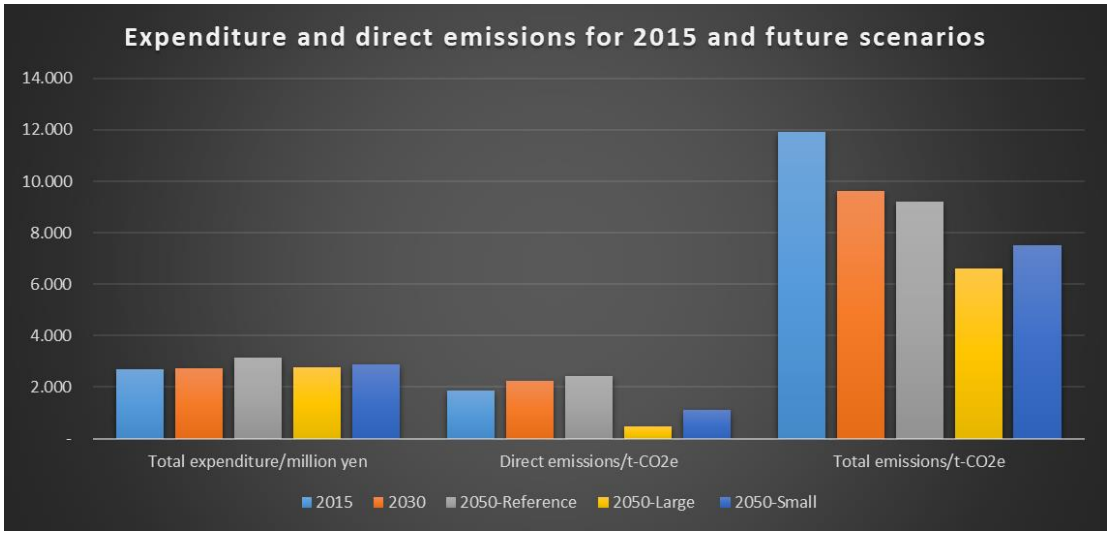

Fig.3. Expenditure and emissions for 2030 and future scenarios.

Discussion

- Compensating effect within a category

The reduced eating out services are compensated by increases of other items in the same category, such as more consumption on commodities required in at-home cooking.

- Slight carbon emissions impacts of consumer behavior changes

Regardless of the extent of these consumer behavior changes, some items or categories will remain stable in emissions they may cause. And consequently, we can regard the corresponding impacts as slight.

- Implication on consumer behavior compatible with reduction goals

Now we may understand that some consumer behavior changes although they can be considered environmentally friendly, do not necessarily lead to a reduction in carbon emissions. In order to cooperate with the government to meet emission reduction targets, consumers can turn their preference towards choices that would produce much less direct emissions. Such as choosing the all-electric house, following the shift from personal vehicle use to public transportations.

Conclusion

This study first uses current expenditure data and inventory data in IDEA to estimate the status quo of household emission, specifically the year 2020, where a large scale of consumer behavior and lifestyle changes occurs. By comparing the 2020 results with 2015–2019 results, some interesting points are revealed, such as compensating effect within one consumption category. Also, other changes in expenditure pattern and emissions in 2020 are specified and interpreted by several possible reasons, based on which we can gain a deeper understanding of household carbon emissions and consumer behavior changes. And then, to explore the possibility of the attainment of Japan's reduction targets for 2030, future inventory data is used to estimate the emission in 2030, while the future expenditure data is obtained by STSM using historical data. The results show that when compared to the year 2015 which can be considered similar to the emissions of 2013, there is only a 25.2% reduction, far from meeting the 66% reduction targets. Finally, keeping the focus on consumer behavior changes, which are applied in building 2050 scenario, this study tries to quantify the impact of consumer behavior changes on expenditure. After expenditure scenarios are built, it

allows us to find several points based on expenditure and emission result from long-term perspectives.

Reference

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