Impacts of rising temperatures on energy demands in local industries: A case in the Saitama Prefecture of Japan

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Abstract

We statistically estimated the impacts of rising temperatures on industrial and commercial energy demands in the Saitama Prefecture of Japan. We formulated a nonlinear relationship between temperature and energy demand using a machine-learning technique. From the sensitivity analysis based on statistically-downscaled climate scenarios, we found that the temperature rise between 2010 and 2050 will increase the total electricity demand by 8.08 PJ (10.44 PJ) under RCP2.6 (RCP8.5), while it will decrease the total fuel demand by 0.15 PJ (0.59 PJ). Electricity demand will increase in 12 industries (e.g., other, machine, and food products manufacturing), and fuel demand will decrease in 8 industries (e.g., cement, metal, and chemical products manufacturing). Energy demand in the machine products manufacturing industry is sensitive to the temperature rise and will increase by 2.94 PJ (3.69 PJ) under RCP2.6 (RCP8.5). The estimated impacts have large variances because the predicted temperature rises are different depending on climate scenarios.

1. Background

- The Saitama Prefecture of Japan suffers from extremely hot summers. The annual average temperature in the Kumagaya city has increased at a rate of 2.1°C per 100 years between 1897 and 2017.
- A temperature rise caused by climate change will influence economic activities of firms through changes in energy demand.
- In this study, we statistically estimated the impacts of rising temperatures on energy demands in 18 industries of the Saitama Prefecture.

2. Model

- We assumed a linear regression model which predicts energy demand by industry from economic and temperature indices (**Figure 1**).
- The candidates for explanatory variables are economic production, energy price, cooling and heating degree-days with various base temperatures, and a dummy variable for the 2011 Tohoku earthquake.
- We cannot use OLS because the number of unknown parameters exceeds the data size (N = 23, see the Data section) and the candidates for explanatory variables are correlated with each other.
- Instead, we used the elastic-net algorithm (**Box 1**; Zou & Hastie 2005) to remove unnecessary explanatory variables from the model.

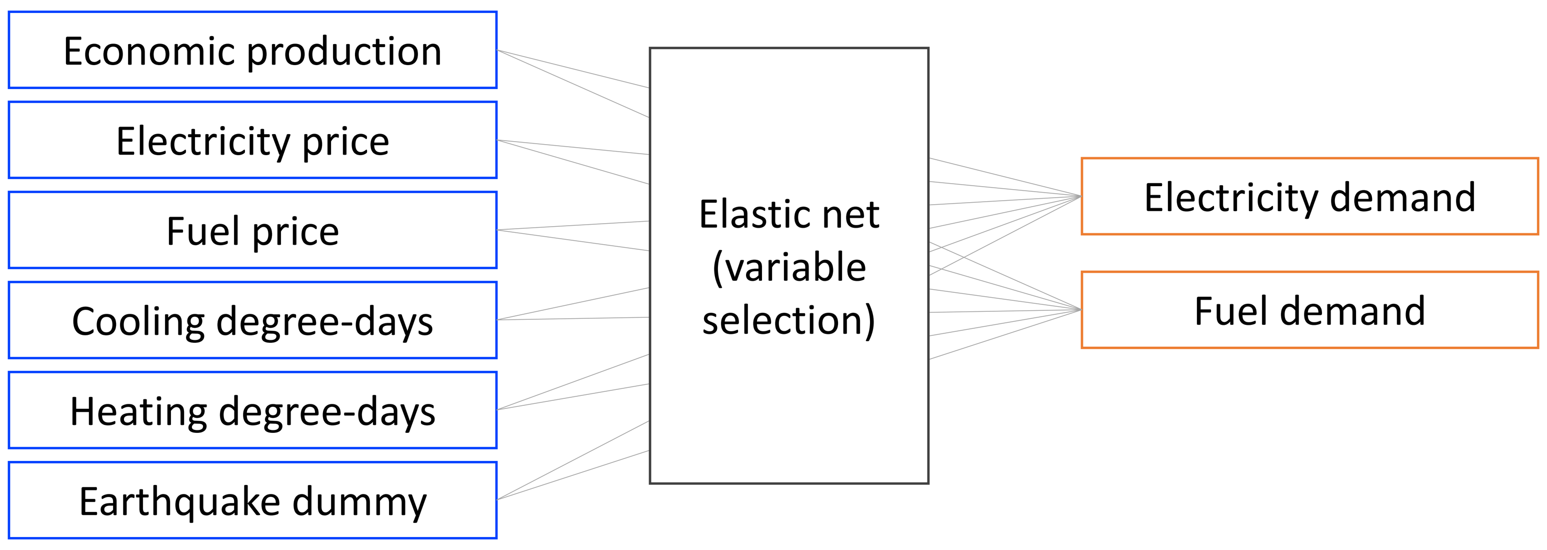

Figure 1: Structure of the energy demand model.

3. Data

Data period: 1990—2012 **Prediction period:** 2026—2050
Region: Saitama Prefecture, Japan **Number of industries:** 18
Climate scenarios: Statistically-downscaled scenarios developed by Dr. Koji Dairaku (University of Tsukuba). We used temperature data computed under the combinations of five GCMs and two RCPs (RCP2.6 and RCP8.5).
Other data sources: R-JIP Database 2017 (RIETI), EDMC Databank (IEEJ), energy demand data of METI, and weather data of JMA.

Box 1: Elastic net

- The elastic net estimates parameters by solving the following problem:

$$\mathrm{argmin}_\beta \left(\|\mathbf{y} - \mathbf{X}\beta\|_2^2 + \lambda \left(\alpha \|\beta\|_1 + (1-\alpha)\|\beta\|_2^2 \right) \right)$$

$\mathbf{y}$	Data vector of a response variable	$\lambda > 0$	Regularization parameter
$\mathbf{X}$	Data matrix of explanatory variables	$\alpha \in [0,1]$	Adjustment parameter
β	Regression coefficient vector		

- Unlike OLS, the elastic net is also applicable to a linear regression model in which the number of unknown parameters exceeds a given data size and the explanatory variables are correlated with each other.

4. Results

- A temperature rise under climate change increases the total electricity demand and slightly decreases the total fuel demand (**Figure 2**).
- The machine products manufacturing industry (MAC) is vulnerable to the temperature rise in the sense that both electricity and fuel demands increase (**Figure 3**).
- The energy demand changes estimated by the sensitivity analysis have large variances because the predicted temperature rises are different depending on GCMs (**Figure 3**).

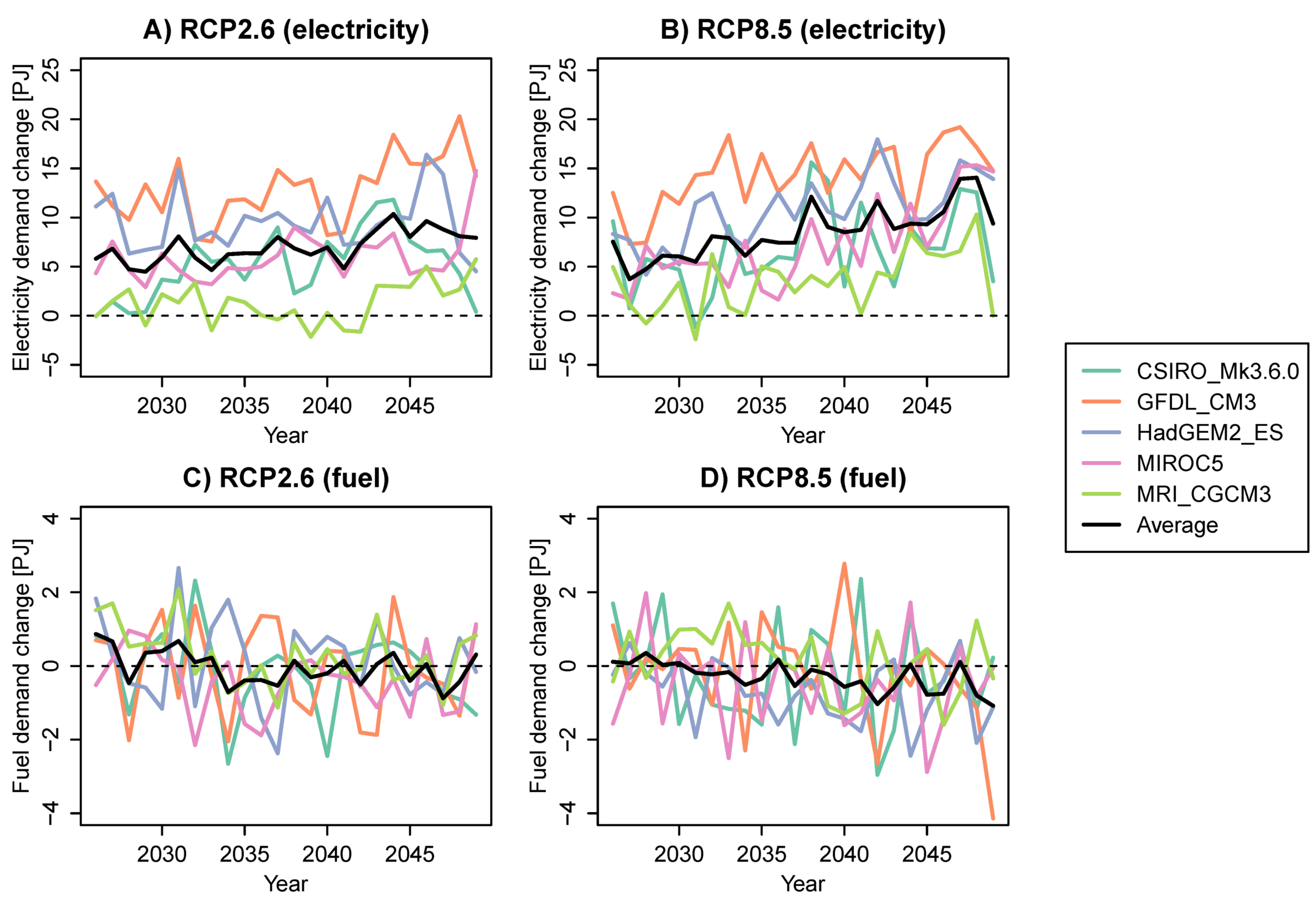

Figure 2: Impacts of rising temperatures on electricity and fuel demands in the whole group of 18 industries, 2026—2050. Changes from the current levels are shown.

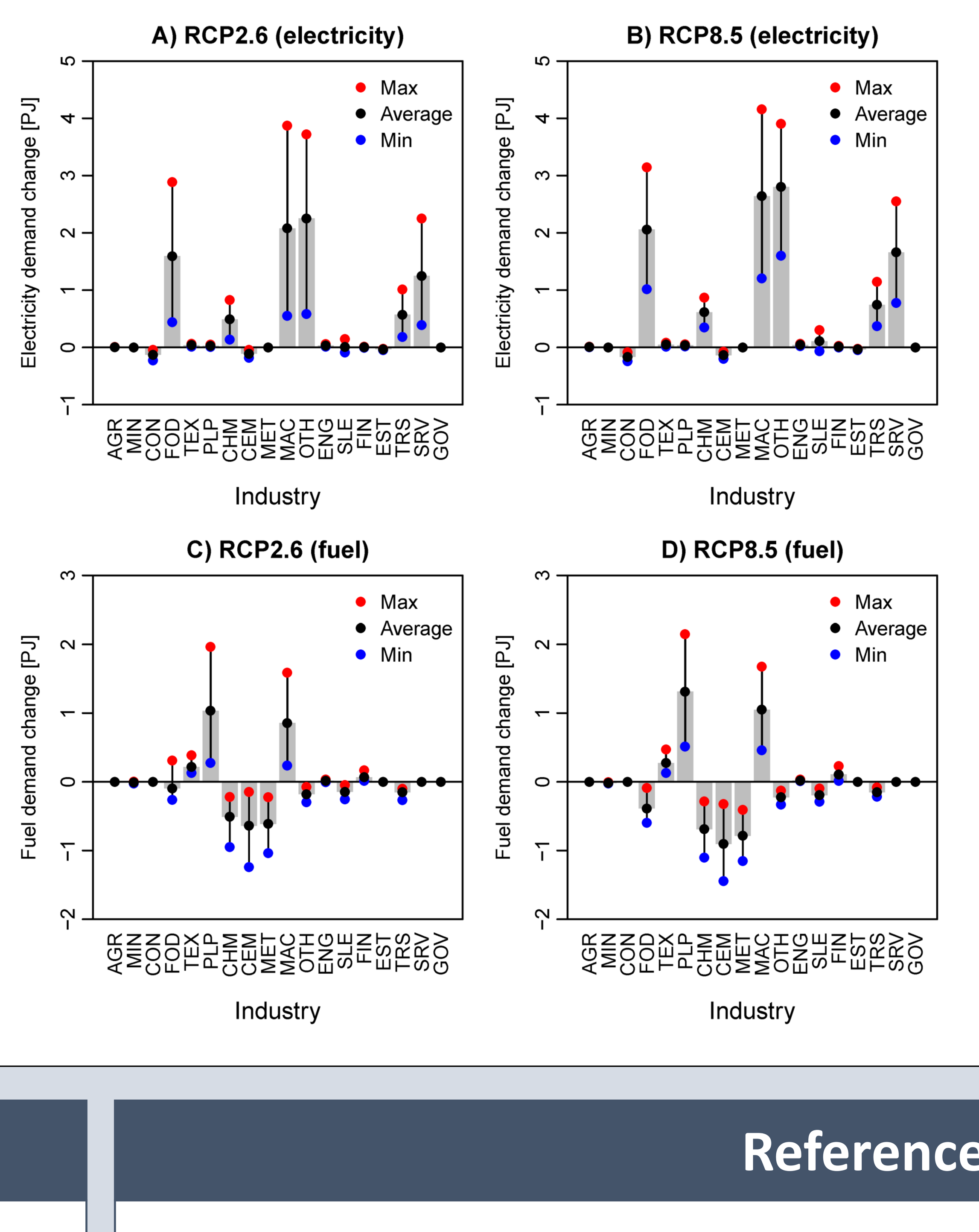

Figure 3: Impacts of rising temperatures on electricity and fuel demands in 18 industries. The average levels in the 2040s are compared with the current levels.

Abbreviation	Industry
AGR	Agriculture, forestry, and fishery
MIN	Mining
CON	Construction
FOD	Food products
TEX	Textile products
PLP	Pulp and paper products
CHM	Chemical products
CEM	Cement and ceramic products
MET	Metal products
MAC	Machine products
OTH	Other products
ENG	Electricity, gas, and water supply
SLE	Wholesale and retail
FIN	Finance and insurance
EST	Real estate
TRS	Transportation and telecommunication
SRV	Other private services
GOV	Government

Acknowledgement

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Reference

1. Zou H and Hastie T, 2005. Regularization and variable selection via the elastic net. Journal of the Royal Statistical Society Series B, 67, 301-320.