Assessing the impacts of climate change on electricity consumption in Japan: The regional and temporal variations in the impacts

Yuki Hiruta, Noriko N. Ishizaki, Shuichi Ashina, Kiyoshi Takahashi

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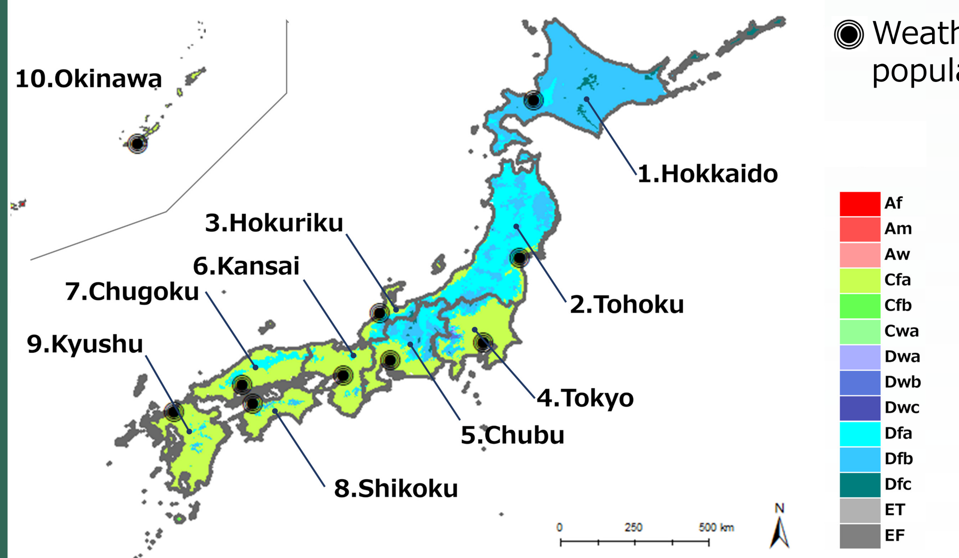
Contact

Yuki Hiruta
hiruta.yuki@nies.go.jp
Social Systems Division,
National Institute for Environmental Studies

I Introduction

Assessing the impacts of future climate change on electricity demand is critical to managing electricity systems efficiently and identifying reliable adaptation measures to mitigate the adverse effects of climate change. This study assessed the impacts of future climate change on electricity demand while considering simultaneous (hourly) interactions among multiple factors and the expected diurnal and seasonal variations of meteorological conditions.

II Materials and Methods



Study area: Ten regions across the wide climate zones of Japan

Projection period : 2020 – 2080

Model training period: 2017 – 2019

- Models that explain the hourly electricity demand by multiple meteorological and human behavioral indicators (Table 1.) were developed
- **Multivariate adaptive regression splines(MARS),** which can consider nonlinear relationships and interactions among variables were used for model construction to capture the simultaneous interactive effects of multiple meteorological factors.
- Hourly future climate scenarios were generated from the bias corrected[1] daily scenarios[2] developed by four GCMs (**GFDL CM3**, **HadGEM2-ES**, **MIROC5**, and **MRI-CGCM3**) for two RCPs (**RCP8.5** and **RCP2.6**).
- The regional and temporal variations of the impacts of future climate change on electricity consumption were illustrated based on projected hourly electricity demand.

Table 1. Data and variables.

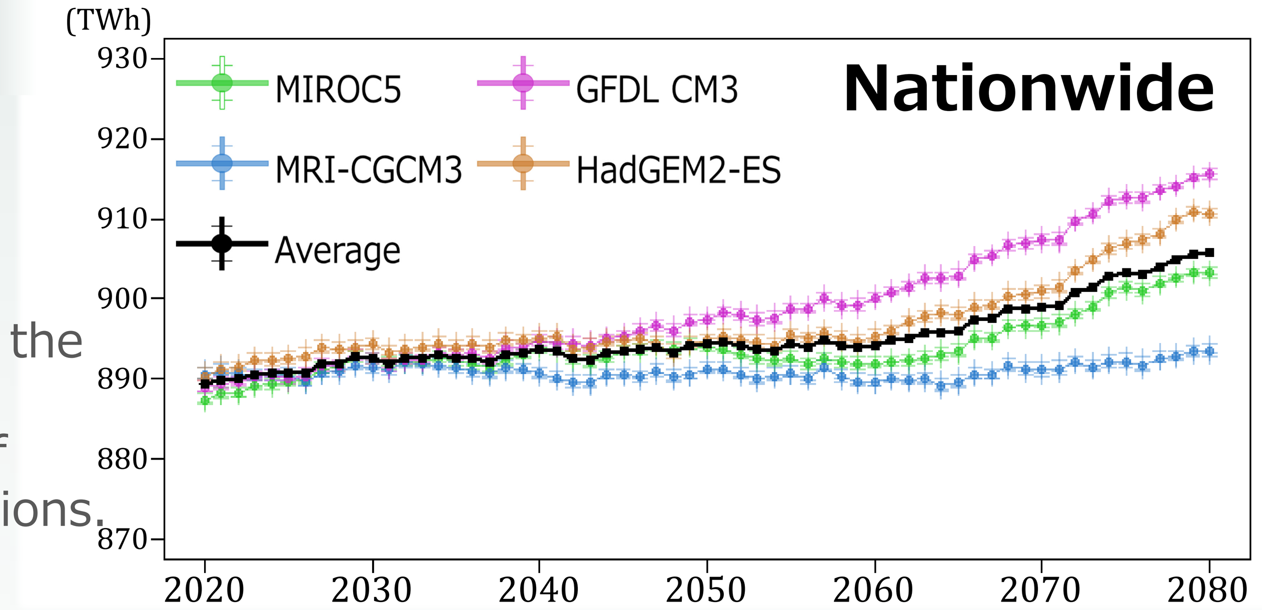
Variable abbreviation			Unit	Variable description
Objective variable [3]		**EC**	MW	Hourly historical **electricity demand** in each electric power company's coverage area.
Candidate explanatory variables	Meteorological indicators [4]	**TEMP**	°C	Hourly average **air temperature**
		SUN	MJ/m²	Hourly total **solar radiation**
		HUM	%	Hourly average **relative humidity**
		RAIN	mm	Hourly total **rainfall**
		WIND	m/s	Average **wind speed** during the ten minutes before each hour
	Thermal comfort indices	**DI**		**Discomfort index.** DI = 0.81 (TEMP) + 0.01 (HUM) (0.99 (TEMP) – 14.3) + 46.3 DI represents the human comfort level in summer [52]
		WCI		**Windchill index.** WCI = (33 – TEMP) (10.45 + 10 (WIND0.5) – WIND) WCI represents how cold air feels on human skin
	Indicators for the daily routine cycle of human activity [5]	**WORK%**	%	Percentage of people who are working at the hour
		AWAKE%	%	Percentage of people awake in their homes at the hour
		SLEEP%	%	Percentage of people asleep at the hour
	Dummy variables that explain the type of days.	**SunD**	-	**Sundays and holidays dummy.** Sundays and holidays were set to one; all other days were set to zero
		SatD	-	**Saturday's dummy.** Saturdays were set to one; all other days were set to zero
		ConD	-	**Consecutive holidays dummy.** Consecutive holidays such as the New Year were set to one; all other days were set to zero
		nWdD		**Non-working day dummy.** Weekends, holidays, the New Year, and the Obon festival were set to one; all other days were set to zero

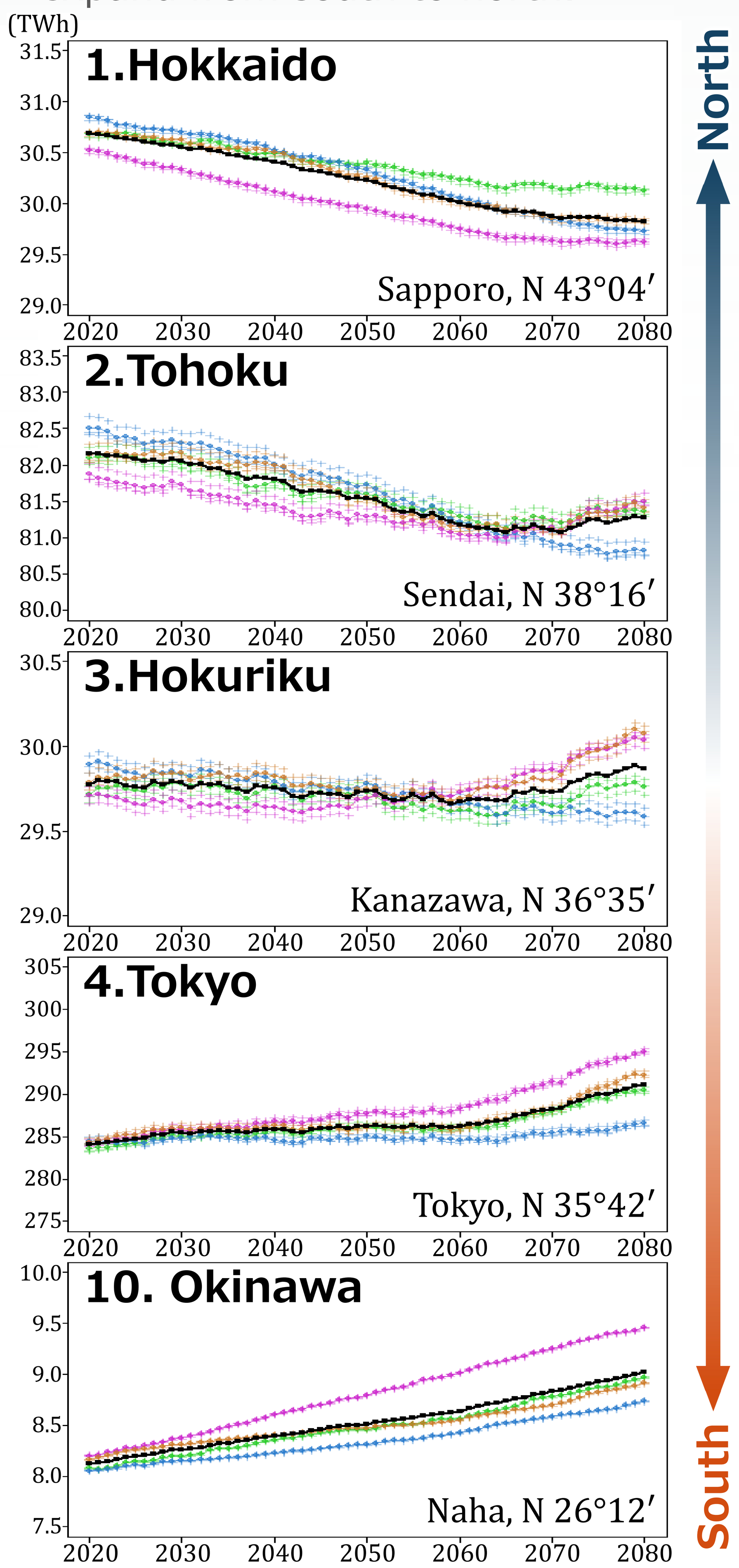
III Results

❶Regional variations in impacts, RCP8.5

The cross-regional net impact was determined by the balance between the decrease of demands for heating in northern regions and the increase of demands for cooling in southern regions.

The region where the impact of climate change was negative (increased demand) will gradually expand from south to north.



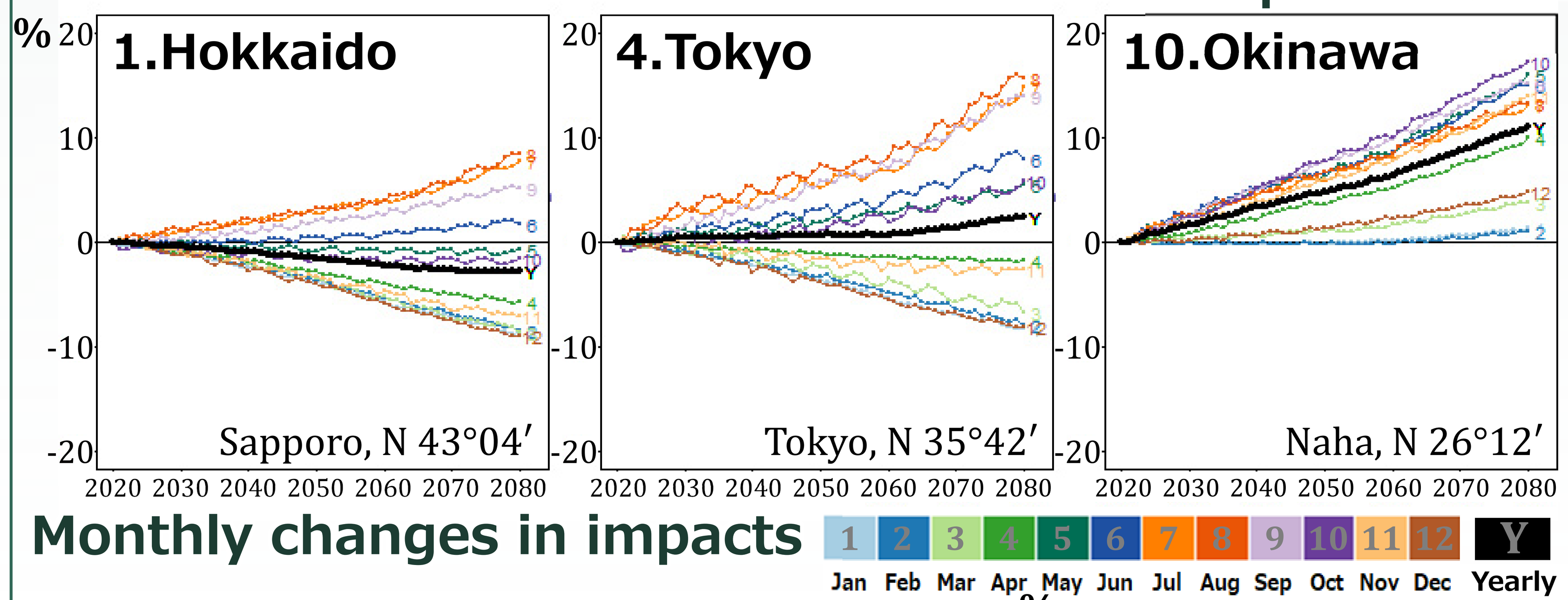


❷Temporal variations in impacts, RCP8.5

Latitude	EPC names	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly (%)	Yearly (TWh)
N 43 04'	1.Hokkaido	-8.6	-8.4	-8.6	-5.7	-0.7	1.7	7.8	8.4	5.2	-1.5	-7.0	-8.9	-2.8	-10.29
N 38 16'	2.Tohoku	-8.5	-8.3	-7.6	-5.0	0.8	2.9	10.3	12.5	8.6	0.9	-5.4	-8.6	-1.1	-10.55
N 36 35'	3.Hokuriku	-8.8	-8.4	-7.6	-4.2	2.7	4.6	13.7	15.3	10.8	2.3	-4.6	-8.3	0.3	1.07
N 35 42'	4.Tokyo	-8.2	-7.8	-6.7	-1.6	5.5	7.9	14.7	15.6	13.9	5.9	-2.6	-8.0	2.4	83.40
N 35 10'	5.Chubu	-7.0	-7.0	-6.4	-1.6	5.3	5.8	12.3	12.3	11.3	4.8	-2.7	-6.6	1.7	27.50
N 34 41'	6.Kansai	-7.9	-8.0	-6.8	-1.5	6.1	8.8	15.5	16.0	15.0	6.6	-2.4	-7.1	3.0	52.35
N 34 24'	7.Chugoku	-7.9	-7.9	-7.1	-2.6	4.6	8.5	16.2	15.7	13.9	4.3	-4.2	-7.8	2.1	15.21
N 33 51'	8.Shikoku	-7.9	-8.1	-6.9	-2.2	4.7	8.5	14.0	13.9	13.8	5.4	-3.3	-7.4	2.0	6.69
N 33 35'	9.Kyushu	-8.1	-7.9	-6.8	-1.8	5.9	9.9	12.5	10.8	13.8	6.2	-3.0	-7.8	2.0	20.11
N 26 12'	10.Okinawa	1.3	1.0	3.7	9.9	16.0	15.0	13.1	13.2	15.0	17.2	13.9	4.8	11.0	10.75
Nationwide		-7.9	-7.8	-6.8	-2.2	4.9	7.3	13.7	14.2	12.9	5.0	-3.1	-7.6	1.8	196.22

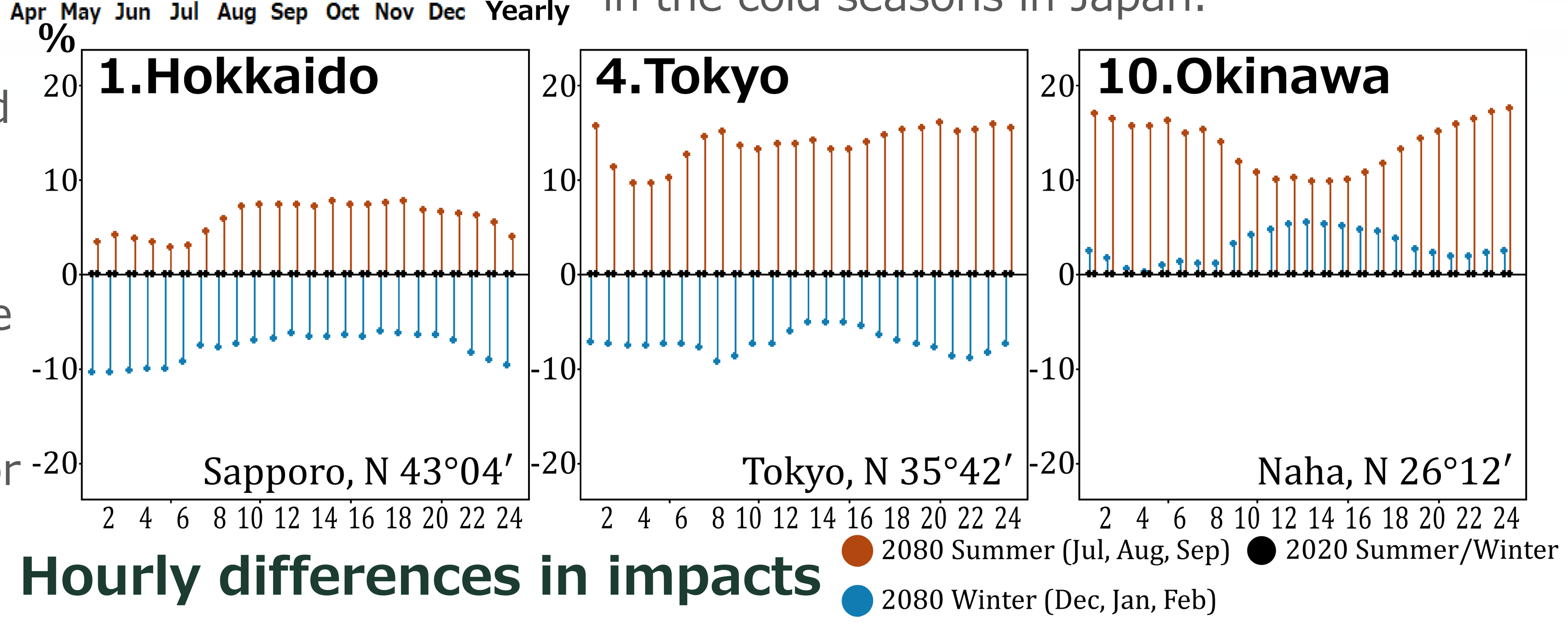
North ↕ South

Impacts from 2020 to 2080 ← Decrease → ← Increase → -20 -10 0 10 20%

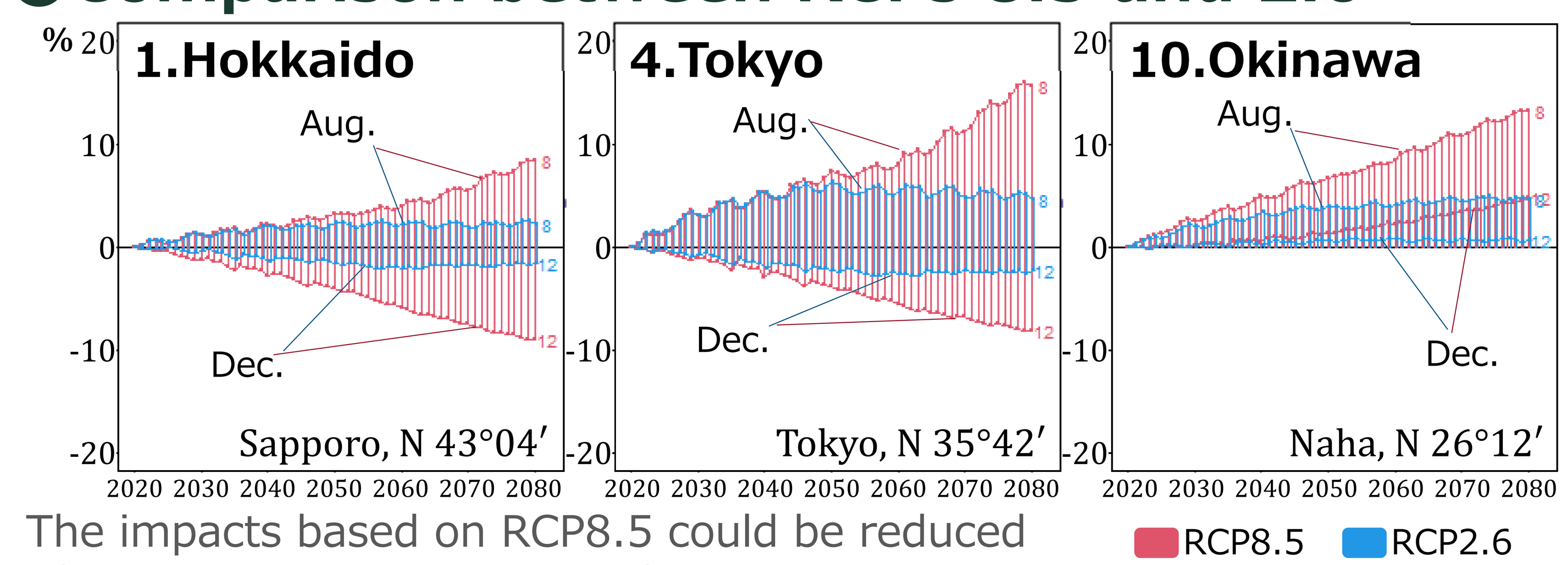


The yearly net impacts in each region were determined by the balance between increased demands in warmer seasons and decreased demands in cooler seasons. Even if the nationwide net increase was negligible, 1.8% (0.3–3.0%), the increases during the hot seasons was projected to increase by 14.2% (10.7–18.0%) and to exceed the decrease of 7.9% (6.8–10.1%) in the cold seasons in Japan.

The impacts could be especially severe in Okinawa. The increase in the most impacted month reached 17.2% (13.3–23.4%). In such areas, climate change not only increased electricity demand during peak seasons and hours but also could extend the seasons and hours associated with the maximum level of demand for cooling. The transition from a decrease of the demand for heating to an increase of the demand for cooling could occur during the winter.



❸Comparison between RCPs 8.5 and 2.6



The impacts based on RCP8.5 could be reduced if the RCP2.6 scenario were followed.

V Limitations

The influences of changing socio-economic conditions were not considered in this study. However, the precise impact of meteorological factors we projected can be used to assess the impacts of other factors by analyzing the difference between future observations and the precise impact of meteorological factors we projected. Future climate scenarios also include uncertainties to be improved.

IV Conclusions

In addition to the progressively larger magnitude of the impacts, climate change was predicted to gradually extend the region and duration (in terms of season and time of day) of greater demand for electricity. The impacts were especially severe in low-latitude areas. However, a maximum level of effort could prevent the most severe negative impacts projected for RCP8.5.

Analysis with a high temporal resolution that considered nonlinearity and interactive effects was useful for assessing the impact of future climate change on electricity demand/consumption in detail.

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