Energy System Analysis

TOHOKU UNIVERSITY

第4世代地域熱供給の国内での課題と可能性

第4世代地域熱供給(4DH)シンポジウム

2019年3月14日

東北大学　大学院工学研究科技術社会システム専攻

中田俊彦

第4世代地域熱供給の国内での課題と可能性

1. 日本のエネルギー情勢と課題
2. 設計アプローチ手法
3. 導入可能性の評価
4. 今後の展開

第4世代地域熱供給の国内での課題と可能性

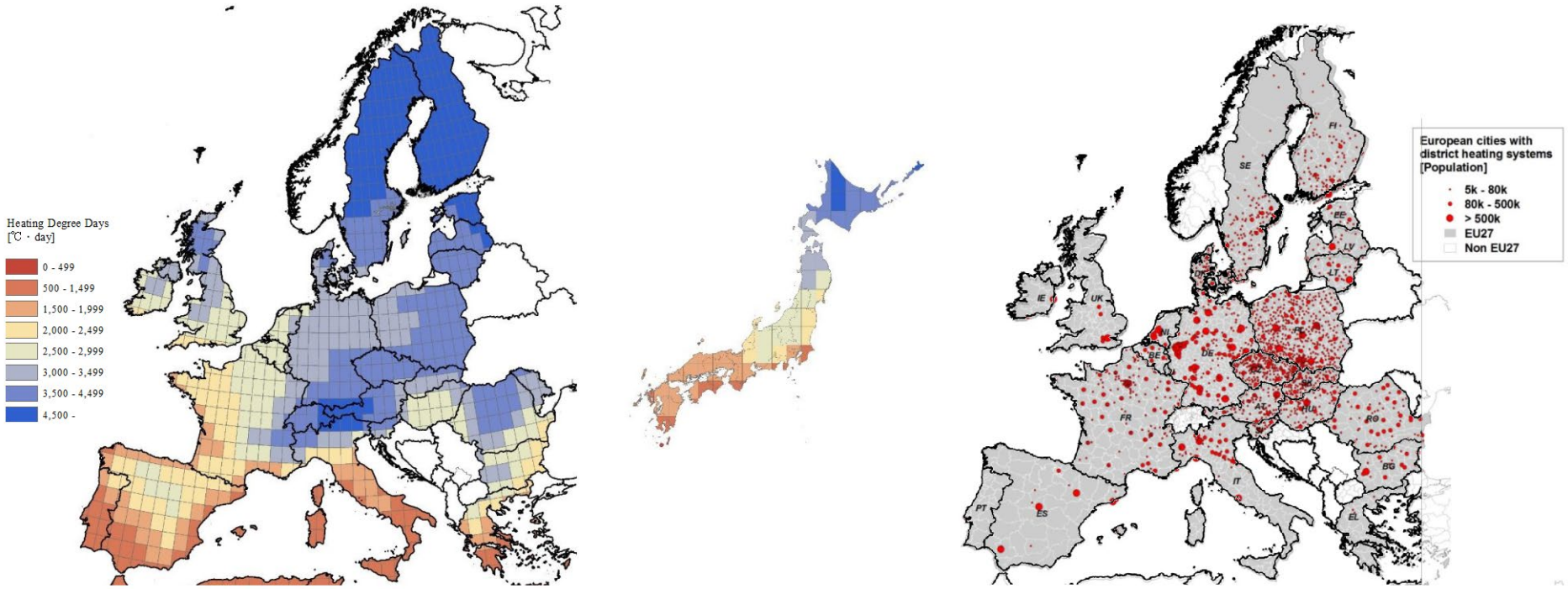
1. 日本のエネルギー情勢と課題


Rebunto Is.
Kunashiri Is.
Etorofu I.
Shikotan Is.
HABOMAI ISLANDS
Sapporo
Okushirito Is.
Aomori
Akita
Morioka
ORTH KOREA
SEA OF JAPAN
Yamagata
Sendai
Sadoshima Is.
Niigata
Fukushima
Takeshima
Toyama
Nagano
Utsunomiya
REPUBLIC OF KOREA
OKI ISLANDS
Kanazawa
Maebashi
Mito
Fukui
Saitama
Tottori
TOKYO
Gifu
Kofu
Matsue
Yokohama
Chiba
Kyoto
Otsu
TSUSHIMA ISLANDS
Okayama
Osaka
Nagoya
Shizuoka
Hiroshima
Oshima Is.
Kobe
Nara
Tsu
Yamaguchi
Takamatsu
Miyakejima Is.
Wakayama
Fukuoka
Tokushima
Matsuyama
GOTO ISLANDS
Saga
Kochi
Oita
IZU ISLANDS
Hachijojima Is.
Nagasaki
Kumamoto
J A P A N
Hizen-Torishima Is.
Miyazaki
Kagoshima
HINA SEA
Tanegashima Is.
Torishima Is.
NORTH PACIFIC O
Yakushima Is.
NANSEI ISLANDS
Oshima Is.
Nishinoshima Is.
OGASAWARA
Chichijima Is.
Hahajima Is.
umejima Is.
Naha

東アジアのガスパイプライン

Interactive World LNG Map © 2017 Petroleum Economist

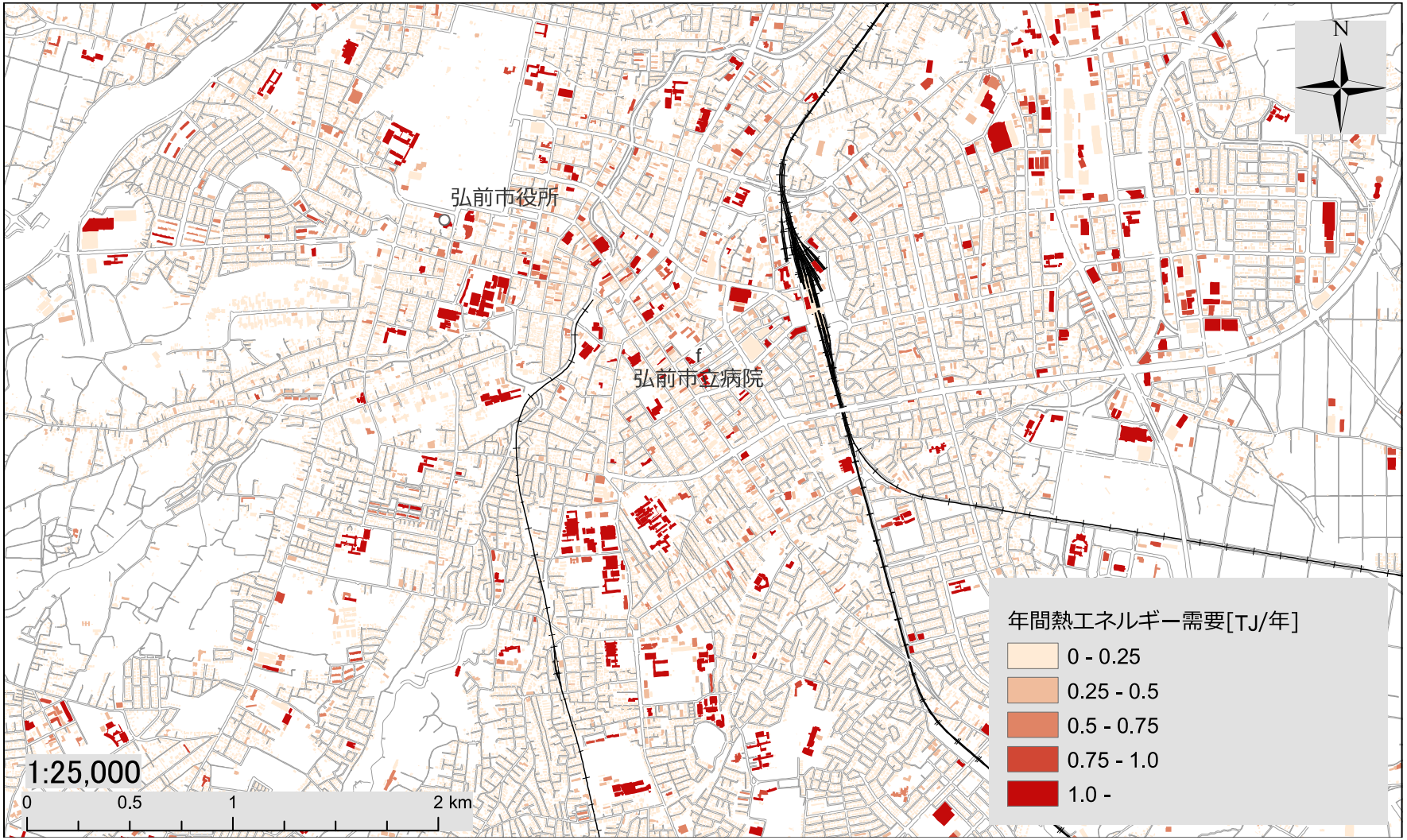
暖房度日と地域熱供給システム導入地域



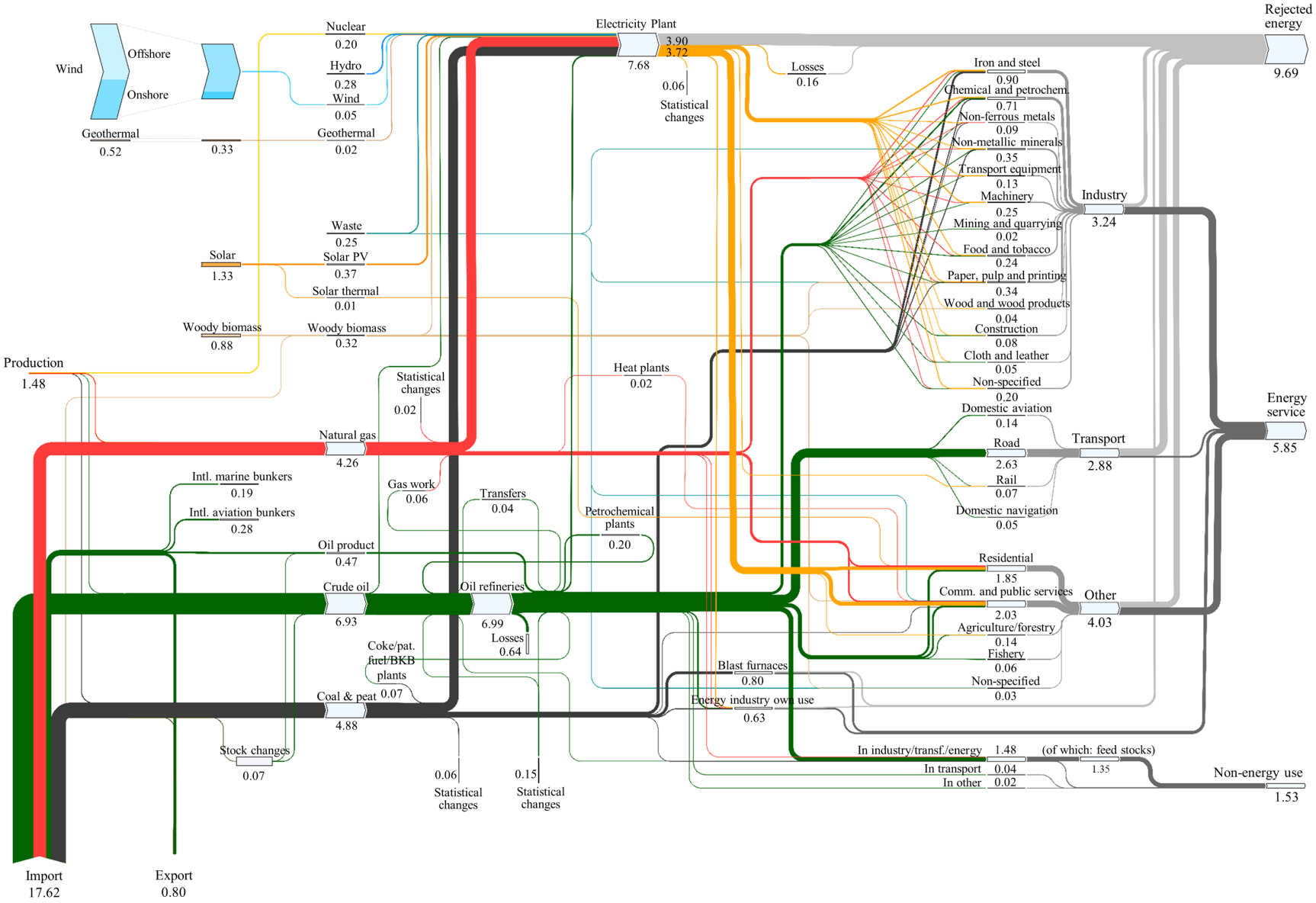
Ref. ：Climate: monthly and annual average heating degree days below 18℃ GIS data at one-degree resolution of the World from NASA/SSE, OpenIE Heat Roadmap Europe 2 Maps, Halmstad & Aalborg Universities, 2013

Above 2500 °C-day
10 prefectures in North Japan

熱需要マップ

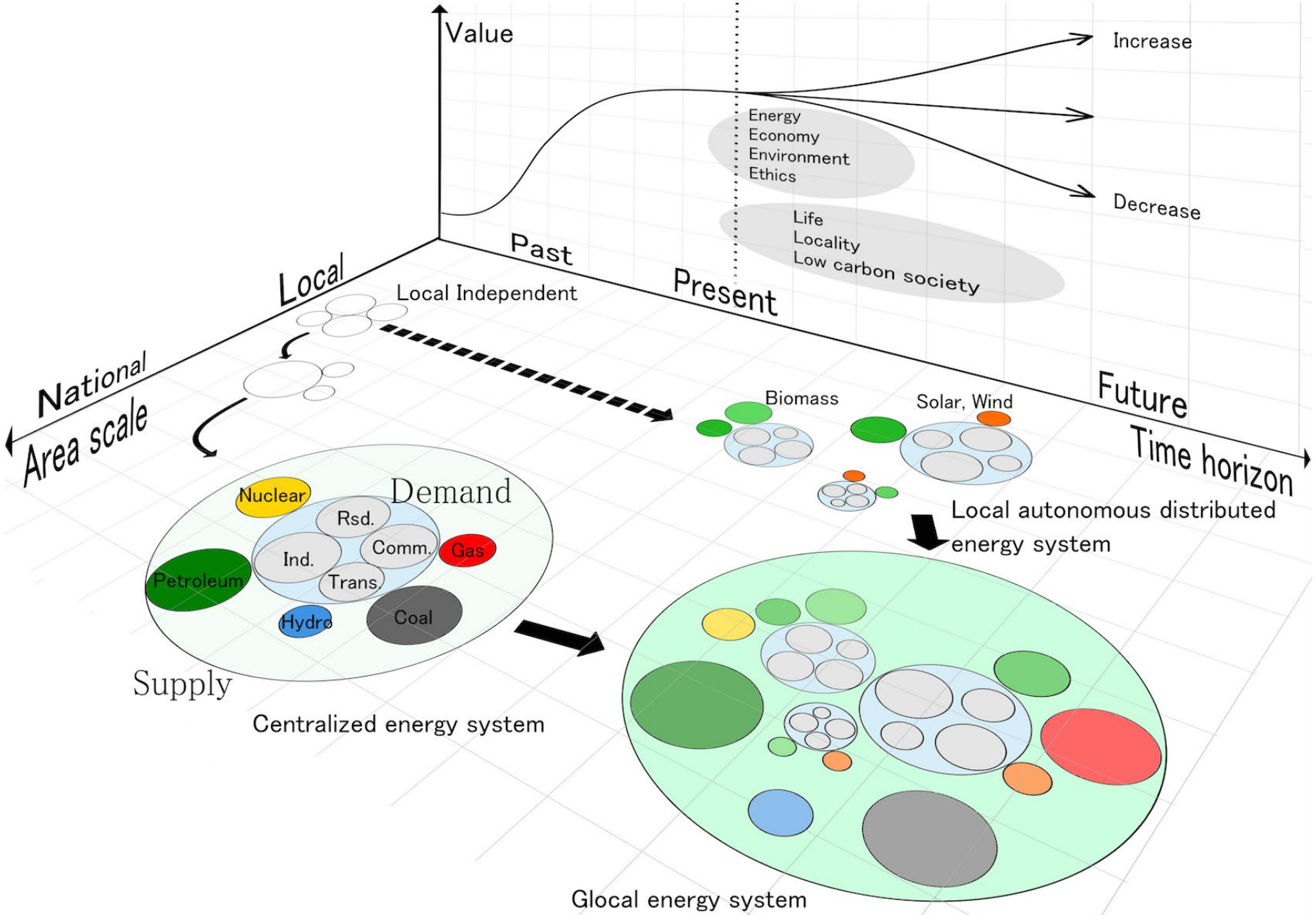

N
弘前市役所
弘前市立病院
年間熱エネルギー需要[TJ/年]
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 -
1:25,000
0
0.5
1
2 km

Japan Energy Flow in 2016



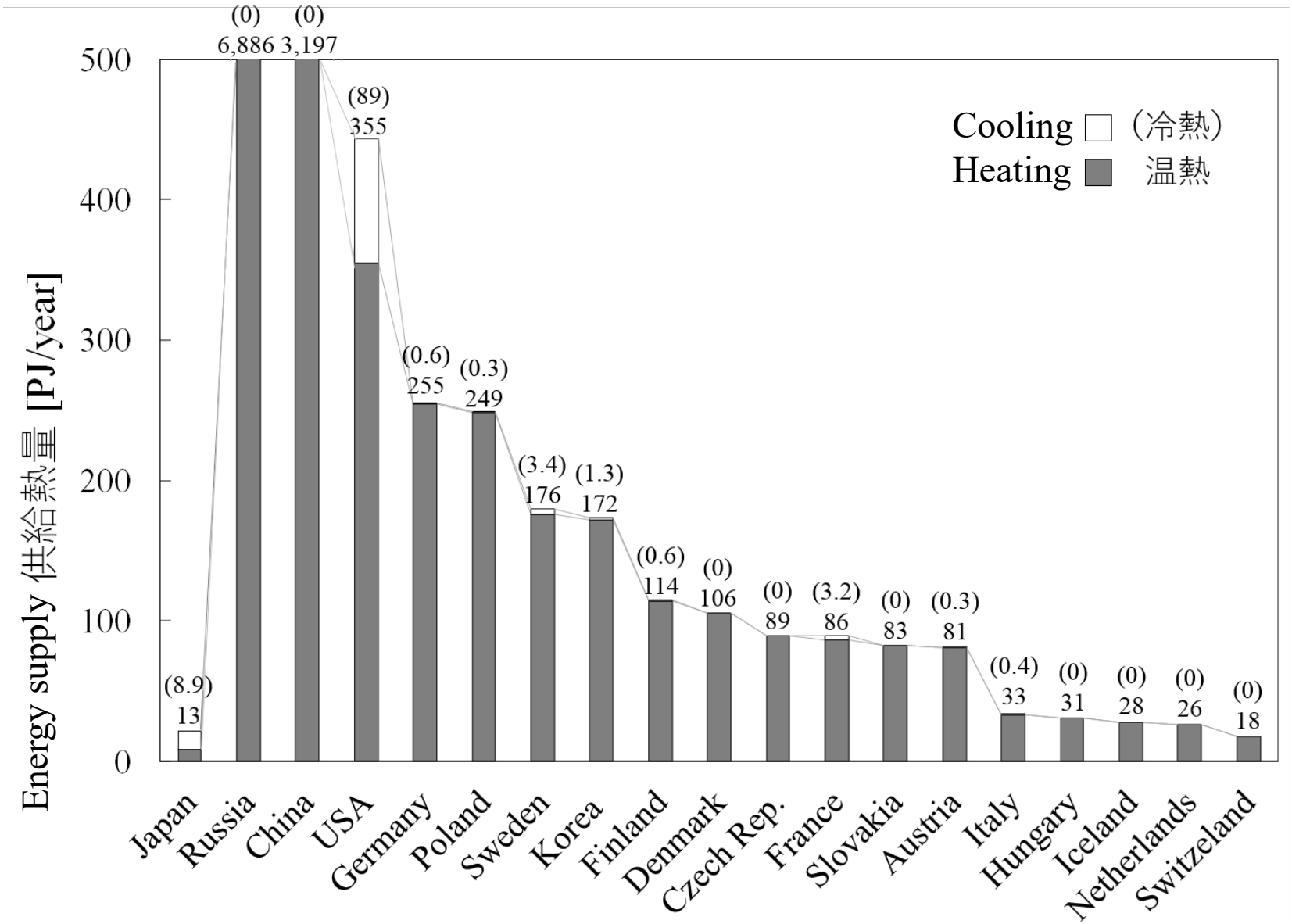
Reference : Japan Agency for Natural Resources and Energy, Energy balance table, FY 2016
Kondo, Energy and energy utilization efficiencies in the Japanese residential/commercial sectors, 2009 etc.

Sep. 18, 2018 H.Onodera@Nakata Lab.



May. 21, 2013 K.Aikawa@Nakata lab.

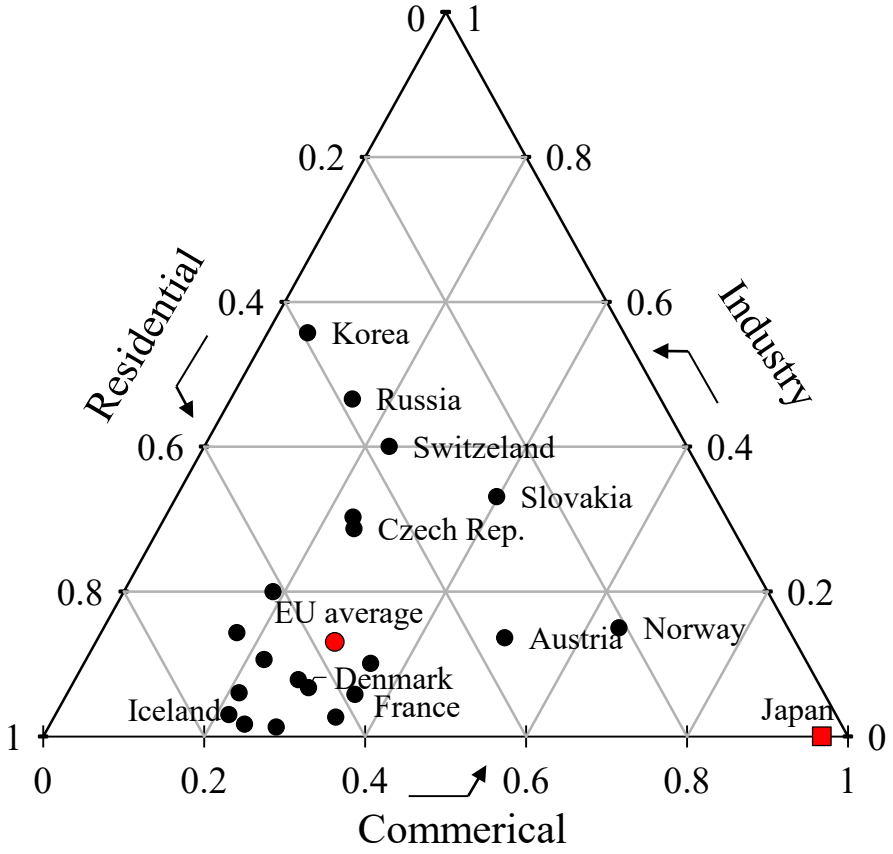
地域熱供給システム導入の国際比較



参考 EUROHEAT & POWER, 2015 Country by country – Statistics overview (2013 data)
熱供給事業便覧 平成28年度版,(社)日本熱供給事業協会, 2017 等

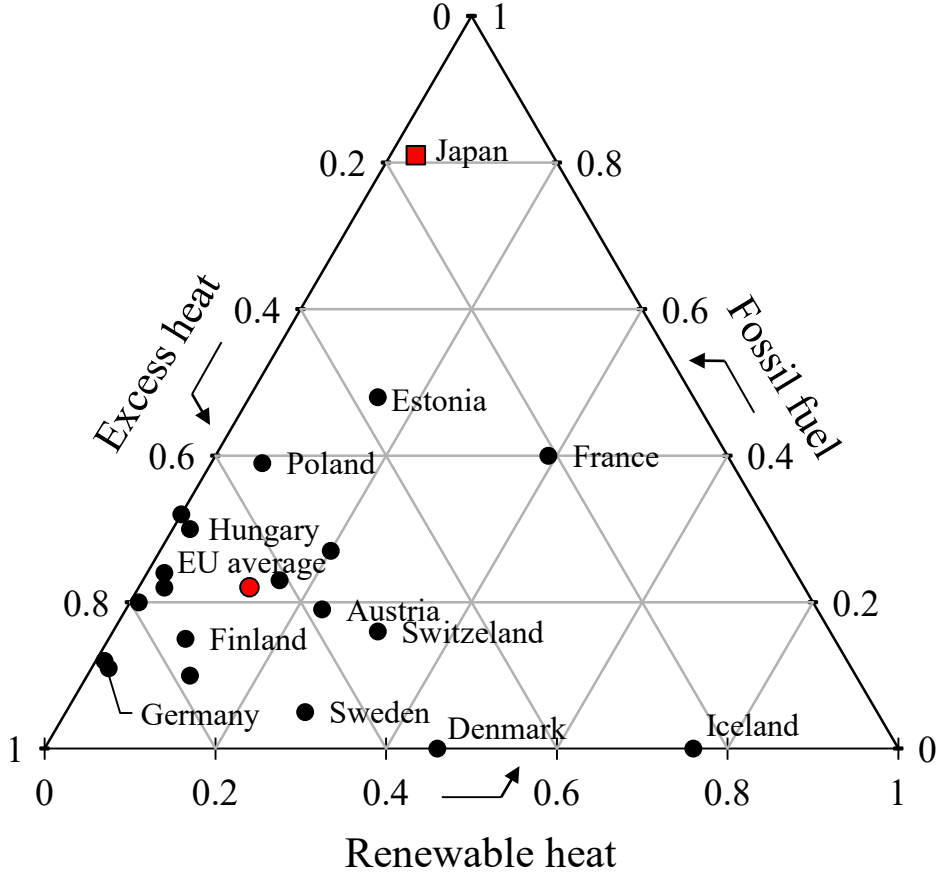
地域熱供給システムの国際比較

需要家



(a) User composition

熱源



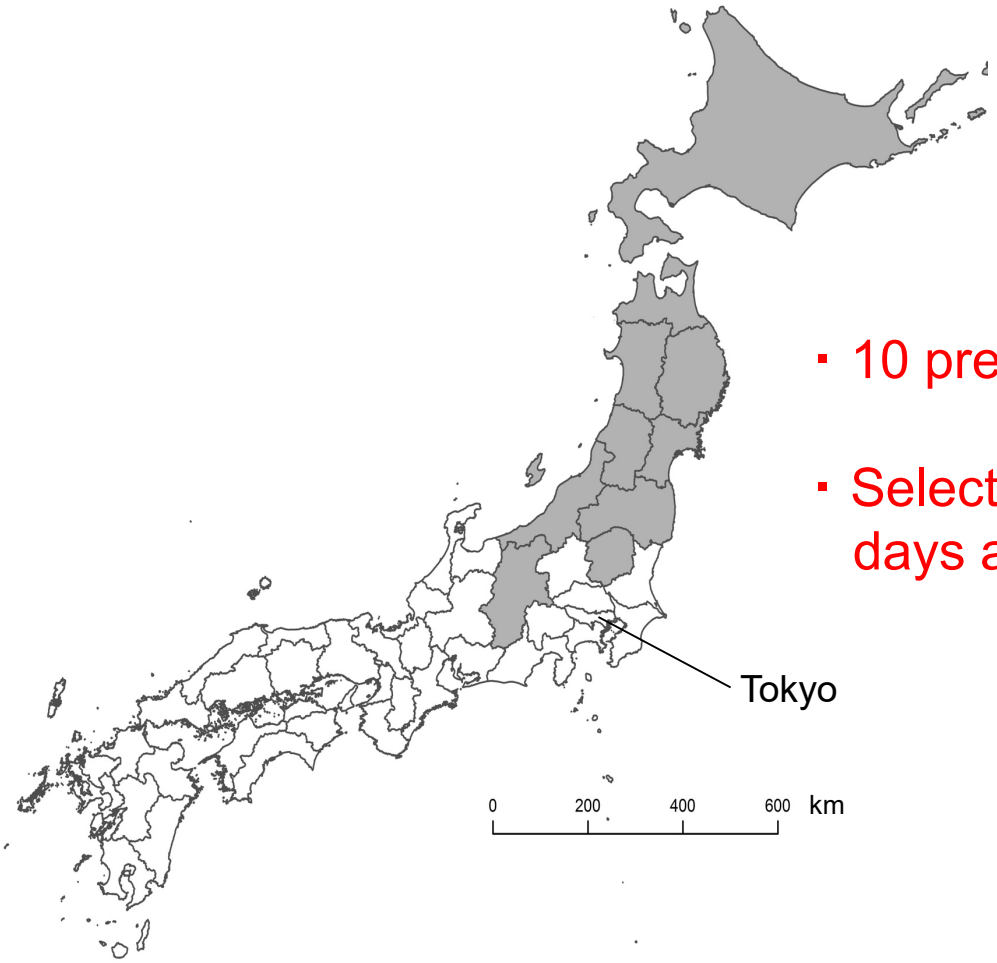
(b) Heat resource composition

Ref. EUROHEAT & POWER, *2015 Country by country – Statistics overview (2013 data),* 2015.
Japanese district heating association, *Handbook of district heating projects*, 2017. et al.

第4世代地域熱供給の国内での課題と可能性

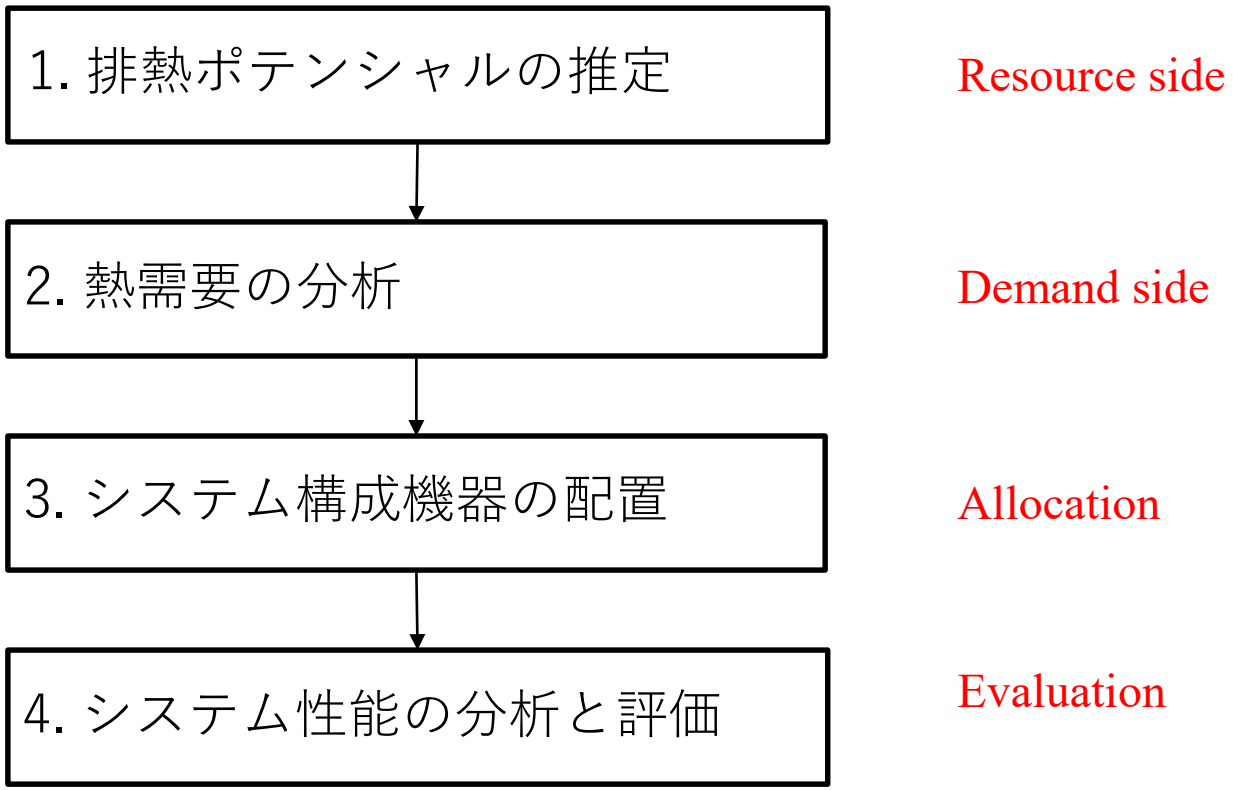
2.　設計アプローチ手法

対象地域



- 10 prefectures in North Japan.
- Selected prefectures' heating degree days are larger than 2,500°C day.

設計手法


1. 排熱ポテンシャルの推定
2. 熱需要の分析
3. システム構成機器の配置
4. システム性能の分析と評価
Resource side
Demand side
Allocation
Evaluation

排熱ポテンシャルの推定

一般廃棄物焼却施設 WIP

$$EX_{\mathrm{WIP},i} = \frac{LHV_{\mathrm{WIP},i} \times m_{\mathrm{WIP},i} \times \eta_{\mathrm{WIP}}}{1000} \quad (1)$$

EX_{WIP}	: Excess heat from waste incineration plants	[TJ/year]
LHV_{WIP}	: Lower heating value	[MJ/t]
m_{WIP}	: Disposal amount of municipal solid waste	[t/year]
η_{WIP}	: Excess heat available rate (= 65%)	[-]
i	: Waste incineration plants	

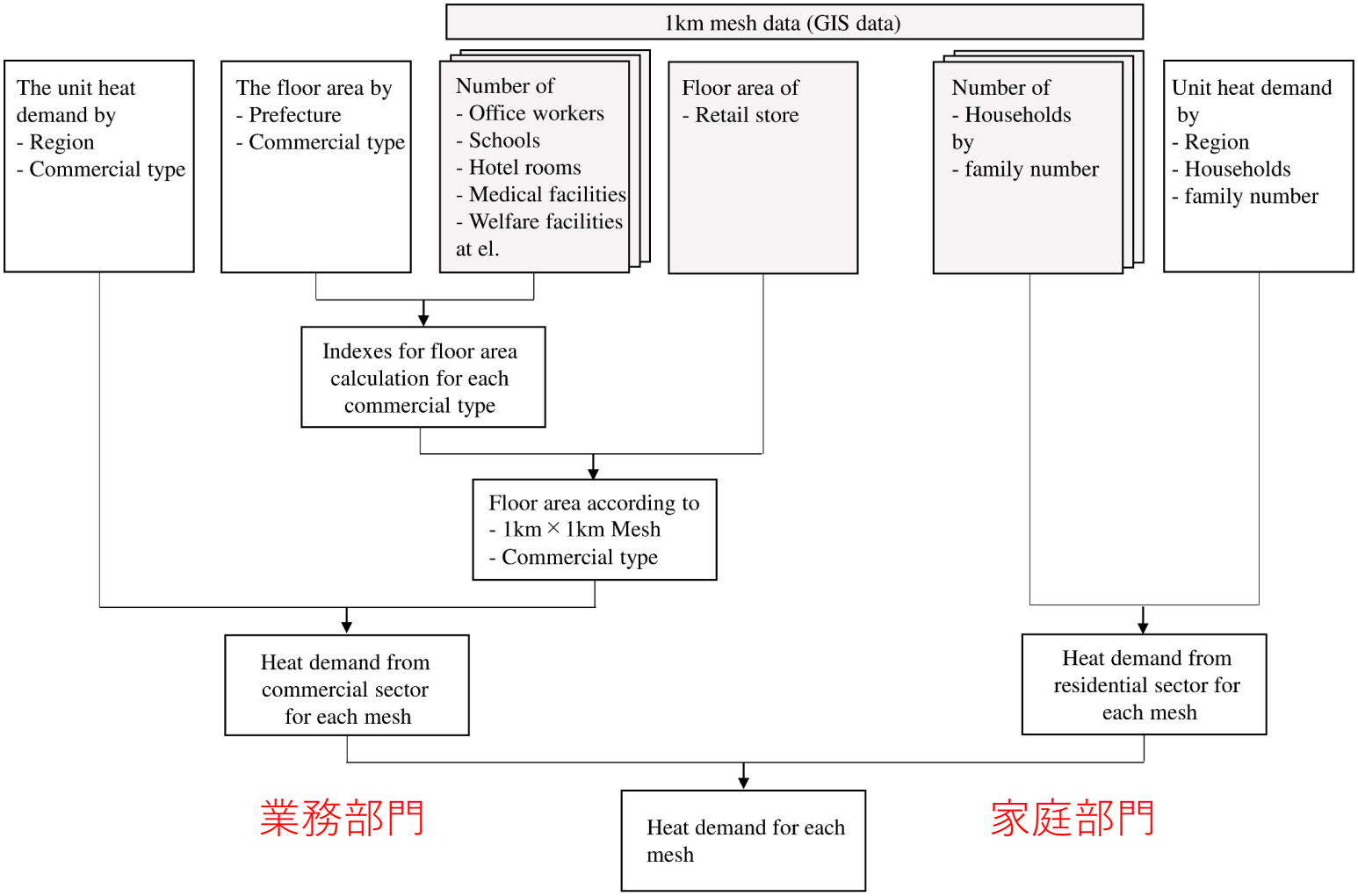
火力発電所 TPP

$$EX_{\mathrm{TPG},j} = \frac{Cap_j \times \eta_{\mathrm{TPG}} \times 8760 \times 3.6}{1000} \quad (2)$$

EX_{TPG}	: Excess heat from thermal power generation	[TJ/year]
Cap_{TPG}	: Plant capacity	[MW]
η_{WIP}	: Excess heat available rate (= 50%)	[-]
j	: Thermal power plants	

Ref. Ministry of Environment, *Research of municipal solid waste disposal situation*, 2017.
Ministry of Land, Information, Transport and Tourism of Japan, *Geographic and quantitative data of waste incineration plants*, 2014.
U. Persson and S. Werner, District heating in sequential energy supply *Appl. Energy*, Vol. 95, pp. 123–131, 2012
Ministry of Land, Information, Transport and Tourism of Japan, *Geographic and quantitative data of thermal power plants*, 2014.

熱需要の分析　1kmメッシュ



熱需要の分析手法

業務部門

$$Q_{\mathrm{com},mesh} = \sum_{type} q_{\mathrm{com},type,mesh} \times Area_{type,mesh} \qquad (3)$$

Q_{com}	: Annual heat demand of commercial sector	[TJ/km^2/year]
q_{com}	: Heat demand unit	[TJ/year/m^2]
Area	: floor area	[m^2/km^2]
type	: commercial type	

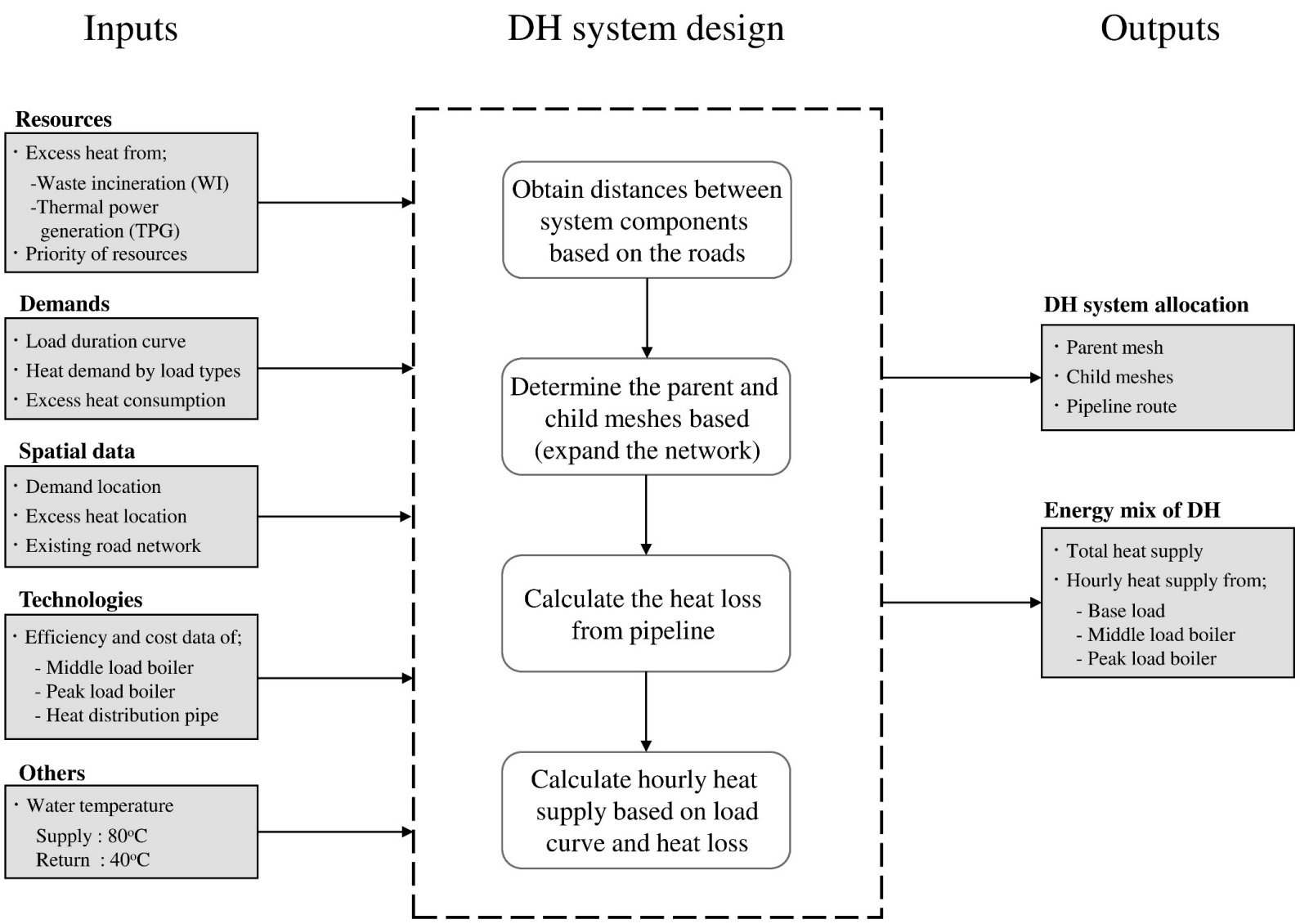
家庭部門

$$Q_{\mathrm{res},mesh} = \sum_{n} q_{\mathrm{res},n,mesh} \times Households_{n,mesh} \qquad (4)$$

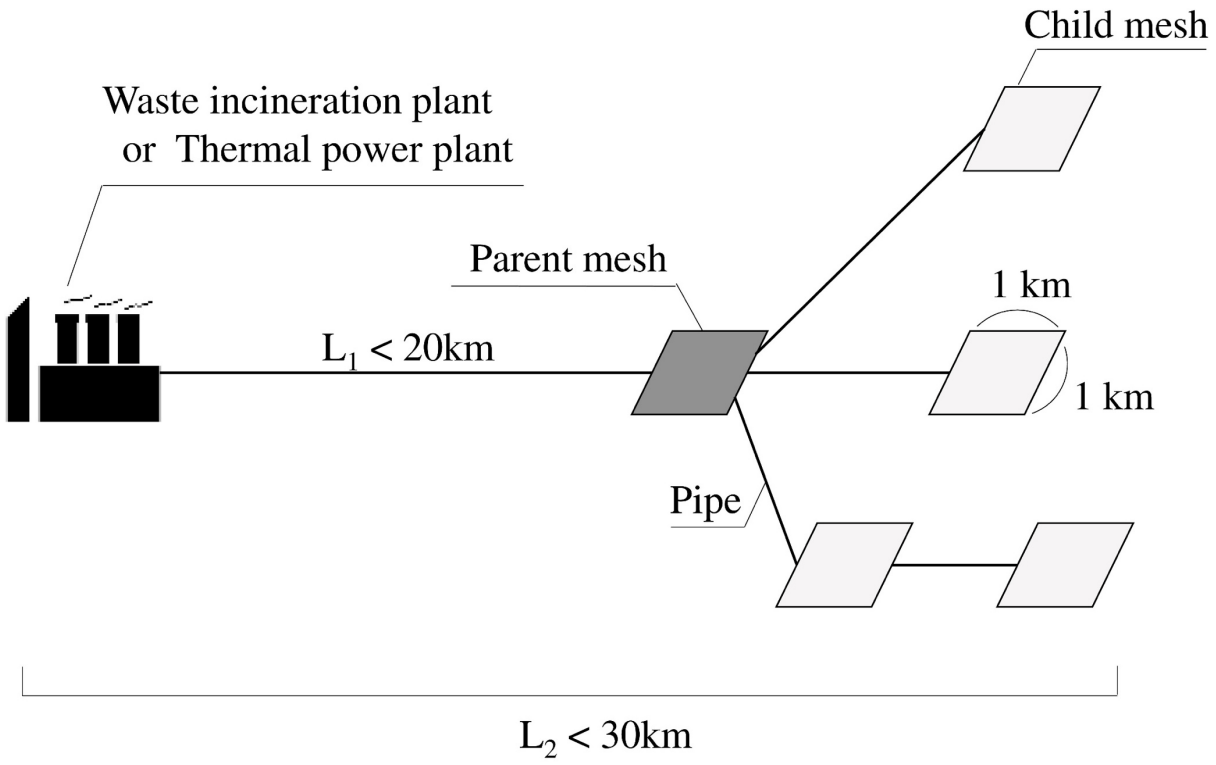
Q_{res}	: Annual heat demand of residential sector	[TJ/km^2/year]
q_{res}	: Heat demand unit	[TJ/year/household]
Housesolds	: Number of household	[household]
mesh	: *mesh*	
n	: family number of household	

Ref. Ministry of Environment, *A survey on the estimation of carbon dioxide emissions from households*, 2015.
Ministry of Internal Affairs and Communications of Japan, *Country affairs statistics 2015*, 2017.
General incorporated association of city environment and energy, *Project 2010, Investigation of potential of installing district heating and cooling*, 1994.
Ministry of Economy, Trade and Industry, *Commercial statistics by mesh in 2014*, 2016. et al.

地域熱供給システムのデザインとモデリング

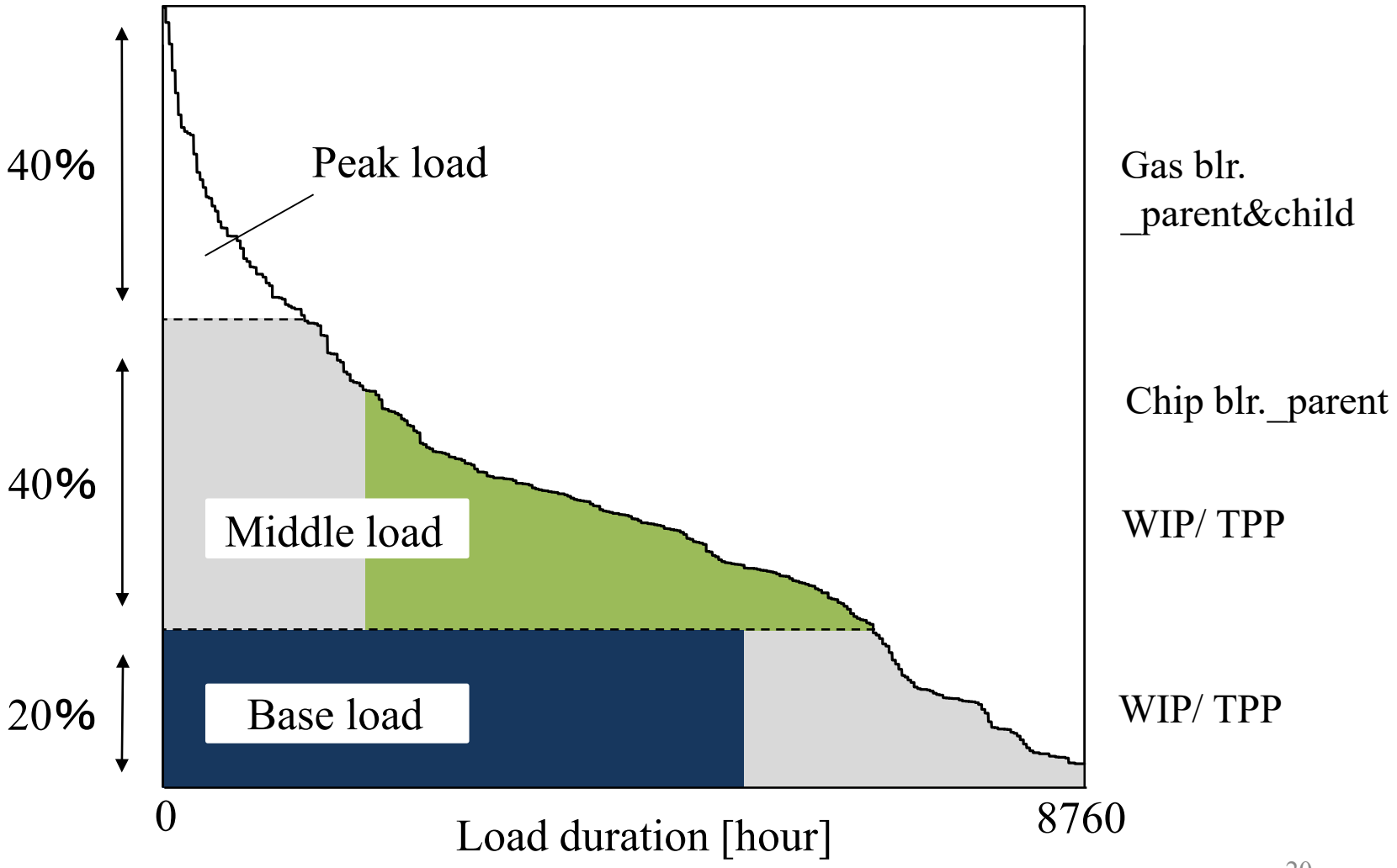


システム構成機器の配置



Parent mesh: Highest heat demand mesh within 20 km from heat resources
Child mesh : LHD_{min} = 1.0 MW/m from the parent mesh

熱負荷曲線の作図


40%
Peak load
Gas blr.
_parent&child
40%
Chip blr._parent
Middle load
WIP/ TPP
20%
Base load
WIP/ TPP
0
Load duration [hour]
8760

技術使用のパラメータ設定

Technology	Units	Capital cost (mmJPY per unit)	O&M (% of capital)	Life time [year]	Scale factor [-]	Efficiency [-]	Fuel cost [JPY/MJ]
Pipe	m	0.039 - 0.205	1.0%	30	-	-	-
Wood chip boiler (Middle load)	MW	91	4.1%	15	0.73	0.80	1.6
Gas boiler (Peak load)	MW	16	0.3%	15	0.73	0.90	2.2

Ref. IEA, *IEA ETSAP - Technology Brief E05 Biomass for heat and power,* 2010.
A. Bejan, G. Tsatsaronis, and M. Moran, *Thermal design & optimization*. 1996.
Asia Biomass Office, Wood pellet production and import, https://www.asiabiomass.jp/topics/1512_02.html
Sendai city gas, Sendai city gas contract, 2017, http://www.gas.city.sendai.jp/family/charge/uploads/2904_sendai_gas_kouri_yakkan.pdf

熱導管の熱損失

$$Loss_{\text{pipe}} = \mathrm{K} \cdot 2\pi \cdot d_a \cdot l \cdot \mathrm{G} \qquad (5)$$

$$d_{\text{a}} = 0.0486 \times \ln\left(\frac{Q_s}{l}\right) + 0.0007 \qquad (6)$$

$$l_{\text{inside},mesh} = 1207.36 \times n_{mesh}^{0.4106} \qquad (7)$$

$Loss_{\text{pipe}}$	:	Heat loss from pipeline	[TJ/year]
da	:	Average pipe diameter	[m]
l	:	Total length of pipeline	[t/year]
K	:	Total heat transmission coefficient (=0.6)	[W/m^{2}k]
G	:	Degree time number of the average distribution difference (=525,600)	[^{o}Cs]
Q_s	:	Heat supply	[TJ/year]
n	:	Building number	[-]

Ref. S. Frederiksen and S. Wener, *District Heating and Cooling*. Studentlitteratur, 2013.
U. Persson and S. Werner, Heat distribution and the future competitiveness of district heating, *Appl. Energy*, Vol. 88, No. 3, pp. 568–576, 2011.
H. Gils, A GIS-based Assessment of the District Heating Potential in Europe, *Graz, Österreich*, No. 2, pp. 1–13, 2012
B. Eikmeier, J. Gabriel, W. Schulz, W. Krewitt, and M. Nast, *Project Report to the German Ministry for Economics and Technology, Bremen/Stuttgart*, 2005.

システムの性能指標の定義

$$\eta_{\mathrm{DH}} = \frac{\sum_{mesh} Q_{mesh}}{Q_{\mathrm{base}} + Q_{\mathrm{middle}} + Q_{\mathrm{peak}} + Loss_{\mathrm{pipe}}} \quad (8)$$

η_{DH}	: Energy efficiency	[-]
Q	: Annual heat demand	[TJ/year]
Q_{base}	: Heat supply for base load	[TJ/year]
Q_{middle}	: Heat supply for middle load	[TJ/year]
Q_{peak}	: Heat supply for peak load	[TJ/year]

$$CO_{2,\mathrm{DH}} = \frac{Q_{\mathrm{peak}} \times \mathrm{CO}_{2,\mathrm{gas}} + E_{\mathrm{pump}} \times \mathrm{CO}_{2,\mathrm{el}}}{\sum_{mesh} Q_{mesh}} \quad (9)$$

CO_2	: CO_2 emission	[g-CO_2/MJ]
E_{pump}	: Electricity consumption	[TJ/year]
$\mathrm{CO}_{2,\mathrm{gas}}$	: CO2 emission from natural gas	[g-CO_2/MJ]
$\mathrm{CO}_{2,\mathrm{gas}}$	: CO2 emission from natural gas	[g-CO_2/MJ]

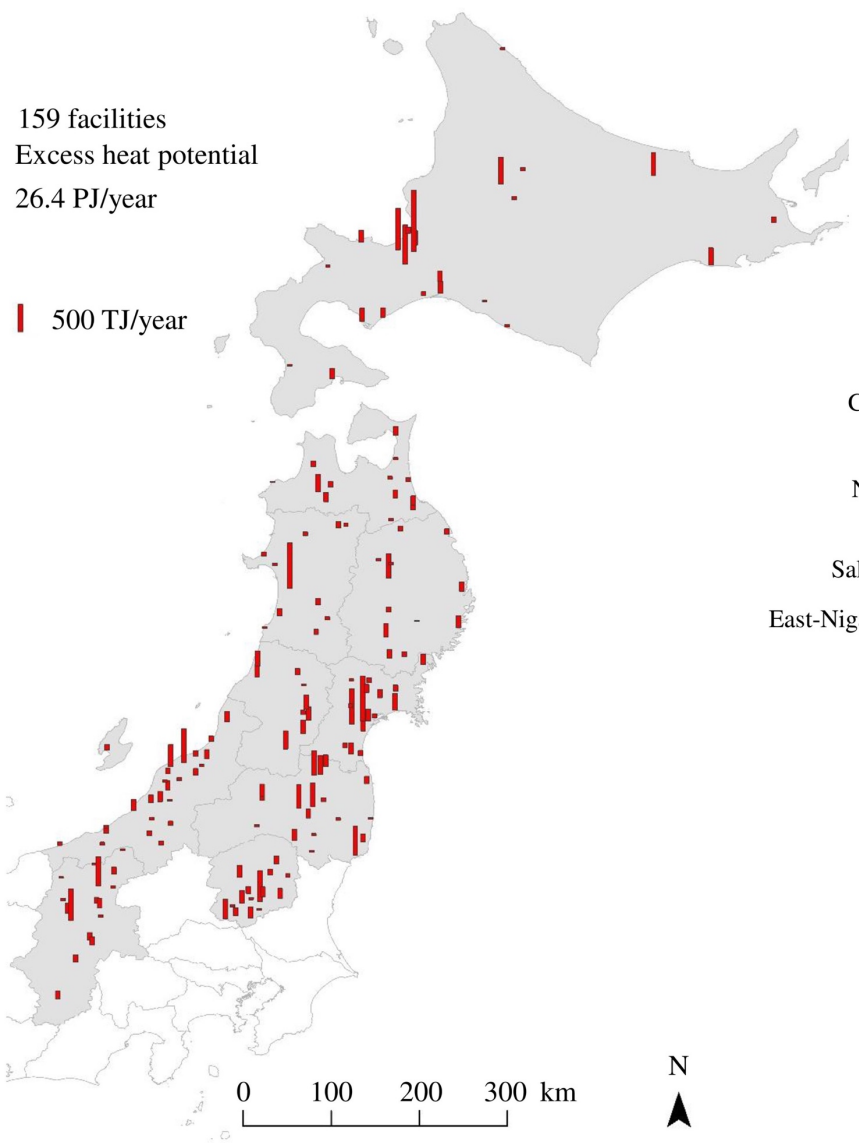
$$Cost_{DH} = \frac{Cost_{\mathrm{capital}} + Cost_{\mathrm{fuel}} + Cost_{\mathrm{O\&M}}}{\sum_{mesh} Q_{mesh}} \quad (10)$$

$Cost_{\mathrm{DH}}$	: Heat supply cost	[JPY/MJ]
$Cost_{\mathrm{capital}}$	: Capital cost	[JPY/year]
$Cost_{\mathrm{fuel}}$	: Fuel	[JPY/year]
$Cost_{\mathrm{O\&M}}$	: O&M cost	[JPY/year]

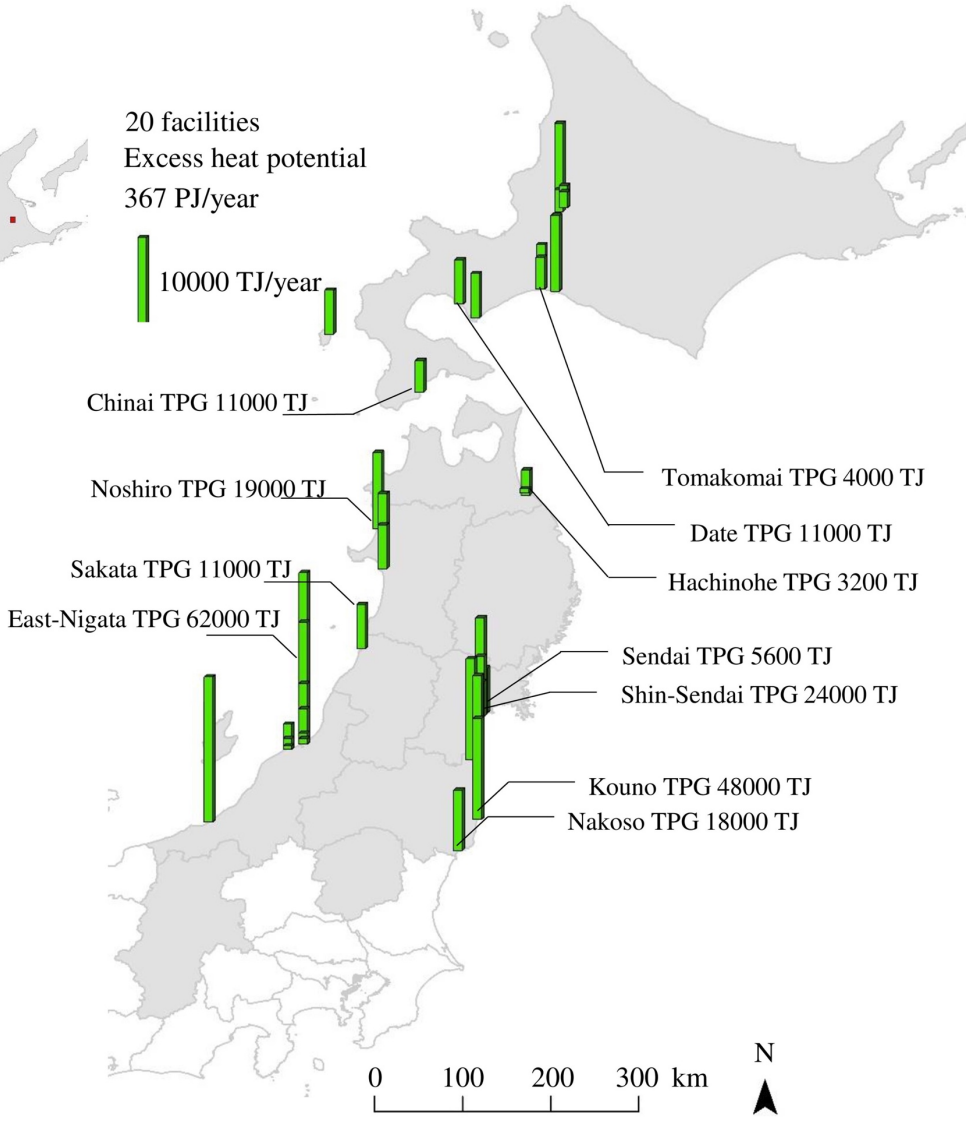
第4世代地域熱供給の国内での課題と可能性

3. 導入可能性の評価

排熱ポテンシャルの地域分布

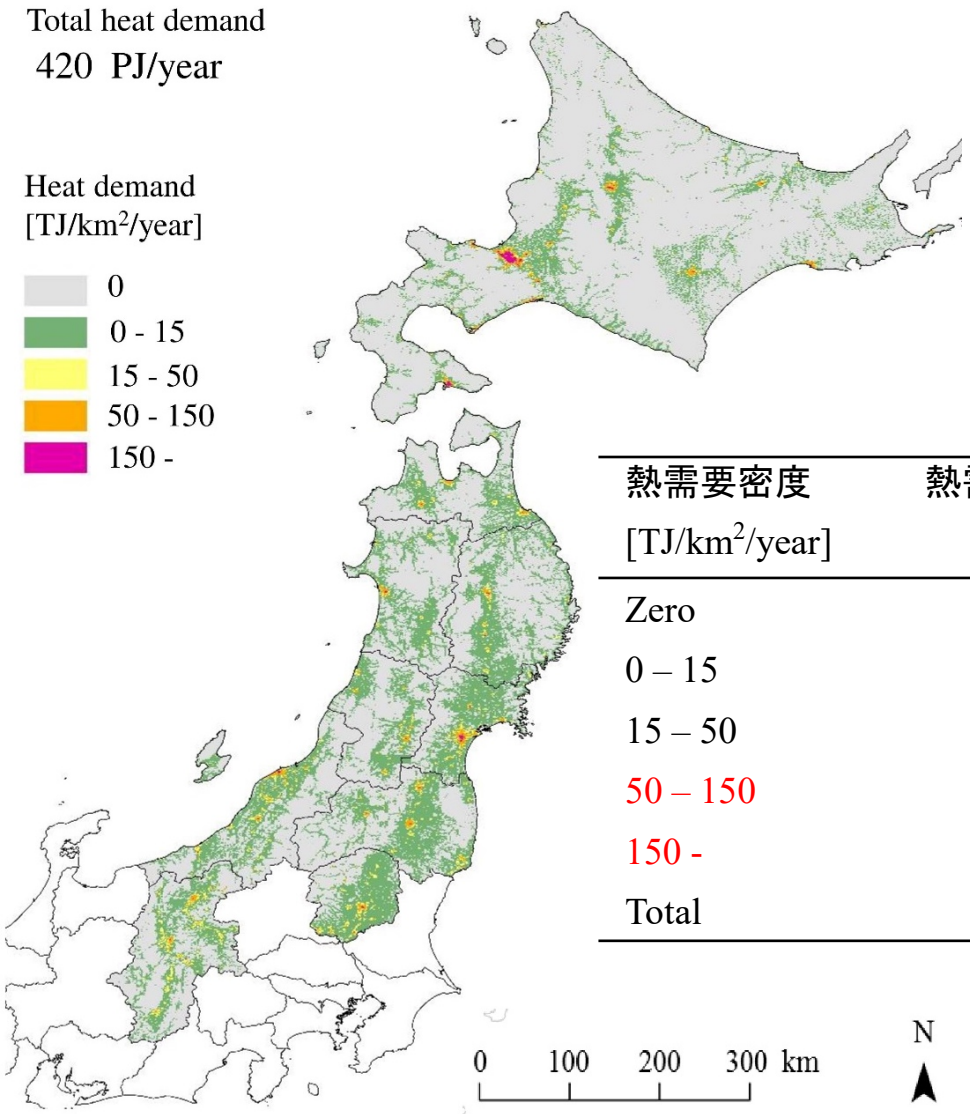


(a) Waste incineration plants



(b) Thermal power plants

熱需要の地域分布



札幌市: 1,110 TJ/km^2/year

熱需要密度 [TJ/km^2/year]	熱需要 [PJ]	需要割合 [%]	面積 [km^2]	面積割合 [%]
Zero	0	0	137,507	70.3
0 – 15	105	25.0	52,086	26.6
15 – 50	107	25.5	3,893	2.0
50 – 150	143	34.0	1,756	0.9
150 -	65	15.5	224	0.1
Total	420	-	195,466	-

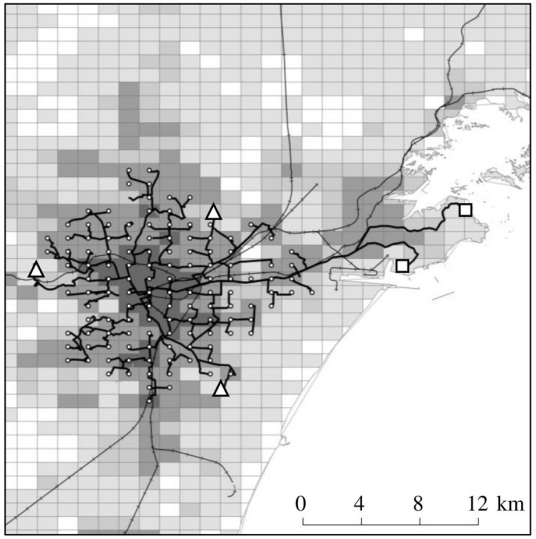
10都道府県毎の分析結果

		Prefecture									
	Unit	Hokkaido	Aomori	Iwate	Miyagi	Akita	Yamagata	Fukushima	Tochigi	Nigata	Nagano
Number of DH	-	26	9	11	14	13	6	17	15	22	16
Energy property											
Total heat supply (A)	PJ	12.7	3.7	2.4	18.1	6.7	3.1	7.4	3.8	8.9	3.9
TPES for systems (B)	PJ	15.6	4.5	3.1	20.4	7.7	3.8	9.2	5.0	10.7	4.9
Average efficiency (A/B)	-	0.81	0.81	0.77	0.89	0.87	0.81	0.80	0.77	0.83	0.79
Excess heat consumption	PJ	8.3	2.8	1.1	16.0	5.8	2.1	5.3	1.8	7.0	1.7
Systems' network											
Total pipeline length	km	2639	1159	807	4690	1717	996	3153	1169	3125	901
District heated area	km^2	126	47	34	166	68	46	122	45	116	33

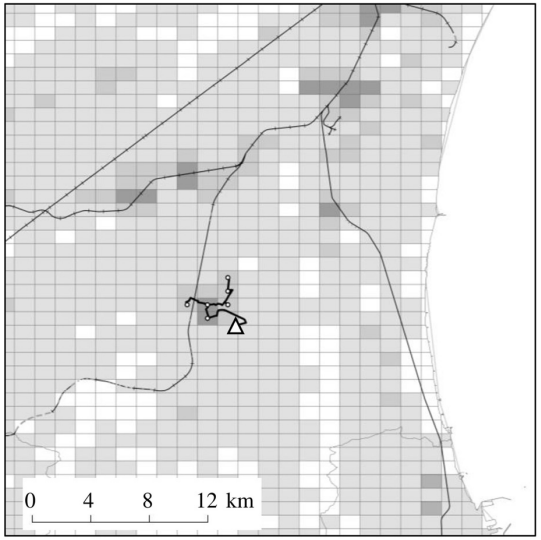
149 DHS in ten prefectures includes;
Hokkaido : 26 DHS with 12.7 PJ
Miyagi prefecture: 14 DHS with 18.1 PJ

東北3地域のケーススタディ

3 WIP
2 TPP
129 meshes
15,800 TJ



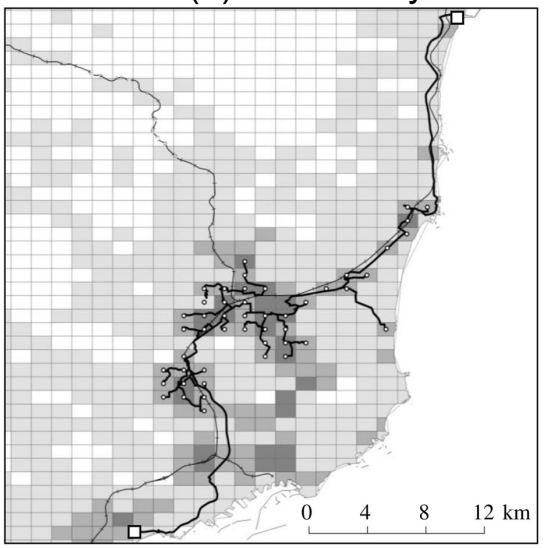
(a) Sendai city



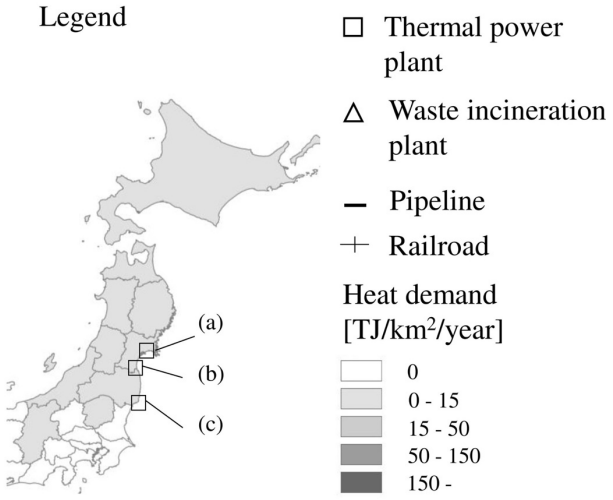
(b) Kakuda city

1 WIP
0 TPP
6 meshes
252 TJ

0 WIP
2 TPP
47 meshes
1,970 TJ



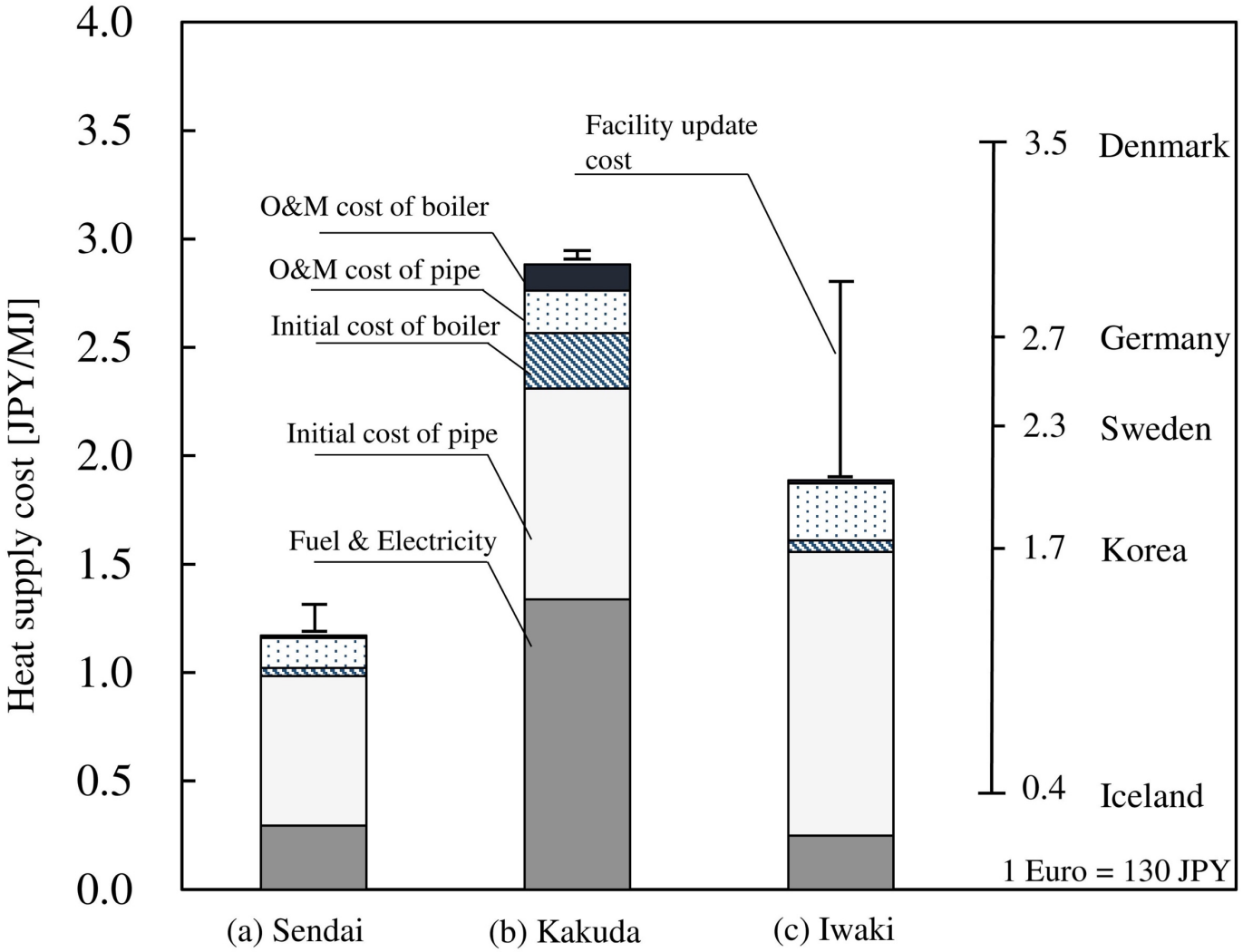
(c) Iwaki city



東北3地域のシステム性能

	Energy efficiency [%]	CO_2 emission [g-CO_2/MJ]	Cost [JPY/MJ]	Total heat supply [TJ/year]	Average LHD [GJ/m]
Sendai city	95.4	7.9	1.2	18085	4.4
Kakuda city	79.9	7.9	2.9	251	3.0
Iwaki city	87.4	6.8	1.9	1970	1.7

費用内訳の比較


Heat supply cost [JPY/MJ]
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Facility update cost
O&M cost of boiler
O&M cost of pipe
Initial cost of boiler
Initial cost of pipe
Fuel & Electricity
3.5 Denmark
2.7 Germany
2.3 Sweden
1.7 Korea
0.4 Iceland
1 Euro = 130 JPY
(a) Sendai
(b) Kakuda
(c) Iwaki

第4世代地域熱供給の国内での課題と可能性

4. 今後の展開

日本への地域実装に向けて

地域熱供給システムは、生活の質QoLの向上、地産エネルギーの熱利用、脱炭素社会の実現、地域経済の効果が期待できる。

- 地域のエネルギー需給フローの把握（エネルギーフロー図の作成）
- 地域のエネルギー需給の分散の分析（エネルギー密度マップの作成）
- システム構成のデザイン