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Impact assessment for rate design of wheeling charge system on electricity transmission sector and household sector with a technology selection model

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1.1 Background

Japan moves toward a low carbon energy system

- The 2015 Paris Agreement: a historic outcome
  Shows a global trend toward decarbonization

- Japan's GHGs reduction target
  2030: 26% reduction from 2013 level
  2050: 80% reduction(maybe net zero)

Fig.1 Paris Agreement

Towards these targets…
The following techniques are required

- Mass adoption of renewable energy
  (PV, Wind power)
- Negative emission technologies
  (Direct Air Capture, CCS,CCU)

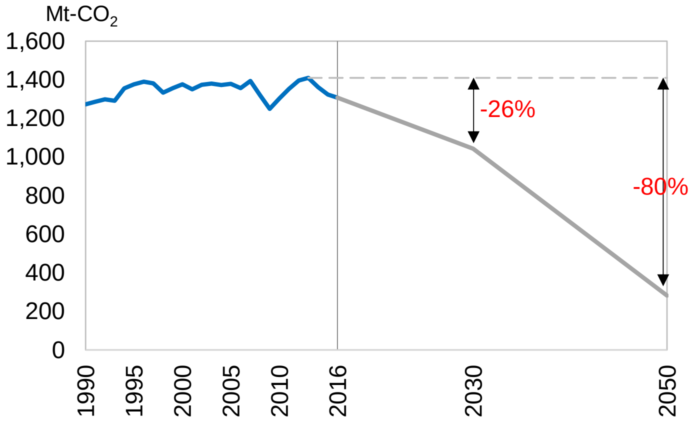
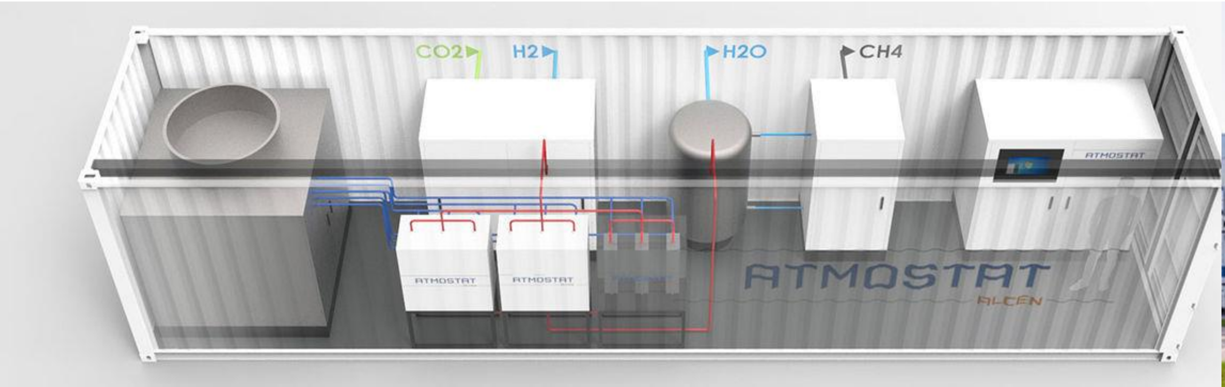


Fig.2 CO2 Emissions and Targets for Japan

DAC and CCU

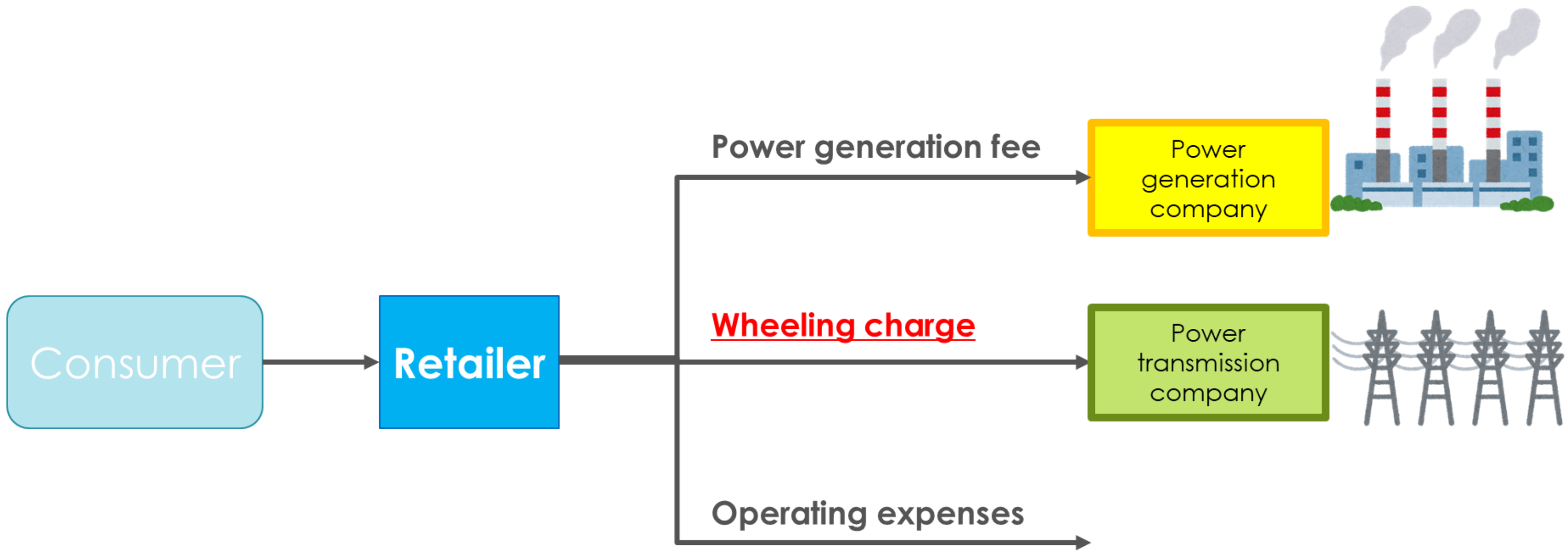
- One of the decarbonization technologies of the future is DAC and CCU.
- On-plant DAC and CCU are already being tested in Germany and other countries[1].
- In theory, it is possible to use each home's air conditioner to perform DAC and CCU.
- Currently, no small devices have been developed to provide DAC and CCU at home.
- In the future, it may be necessary to perform DAC and CCU in households for decarbonization.



Small module to perform DAC and CCU[1]

[1] STORE&GO; https://www.storeandgo.info/

1.2 Wheeling Charge System



<Fee design for wheeling charge>

- Distribution of costs among the transmission and distribution equipment costs, according to the contracted power, to extra high voltage, high voltage and low voltage.
- The home sector is classified as a low voltage.
- A combination of basic and meter rates.

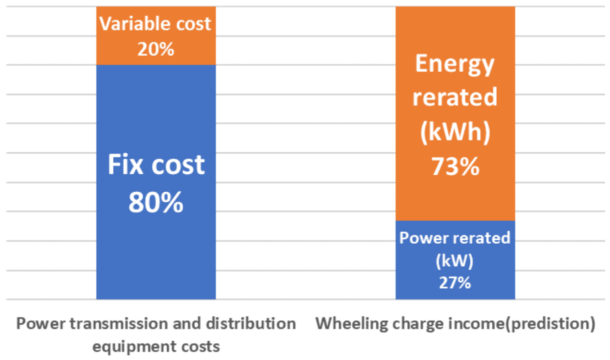


Fig.4 Comparison of the breakdown of transmission and distribution costs and transmission charge revenues

1.2 Wheeling Charge System

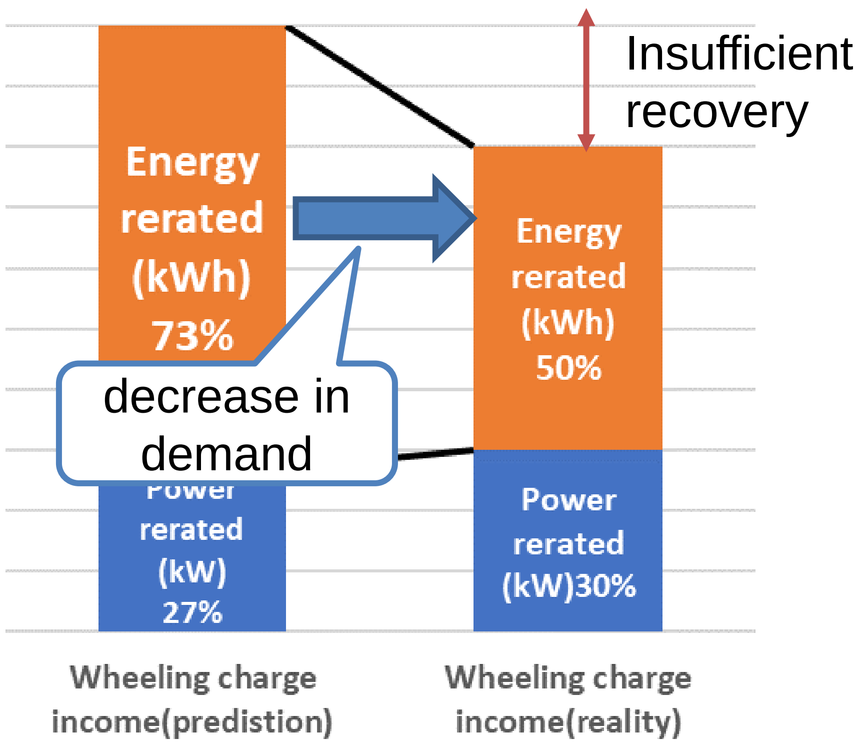


Fig.5 Possibility of under-recovery of transmission charges

Decrease in grid usage due to PV and storage batteries

Mainly transmission and distribution costs are recovered from energy rerated components, so there is a possibility that they will not be recovered.

The unit price of transmission charges will increase.

1.3 Research objective

Objective

- Evaluation of the appropriate recovery of transmission and distribution costs through the revision of the transmission tariff system
- The impact of that revision on demand response technology.
- Impact of the revision on Residential PV
- Assessing the contribution of negative emission technologies

Approach

Based on the bottom-up technology selection model, an improved version of the model will be used that considers the institutional design of the wheeling charge system and the consumption dynamics of the residential sector.

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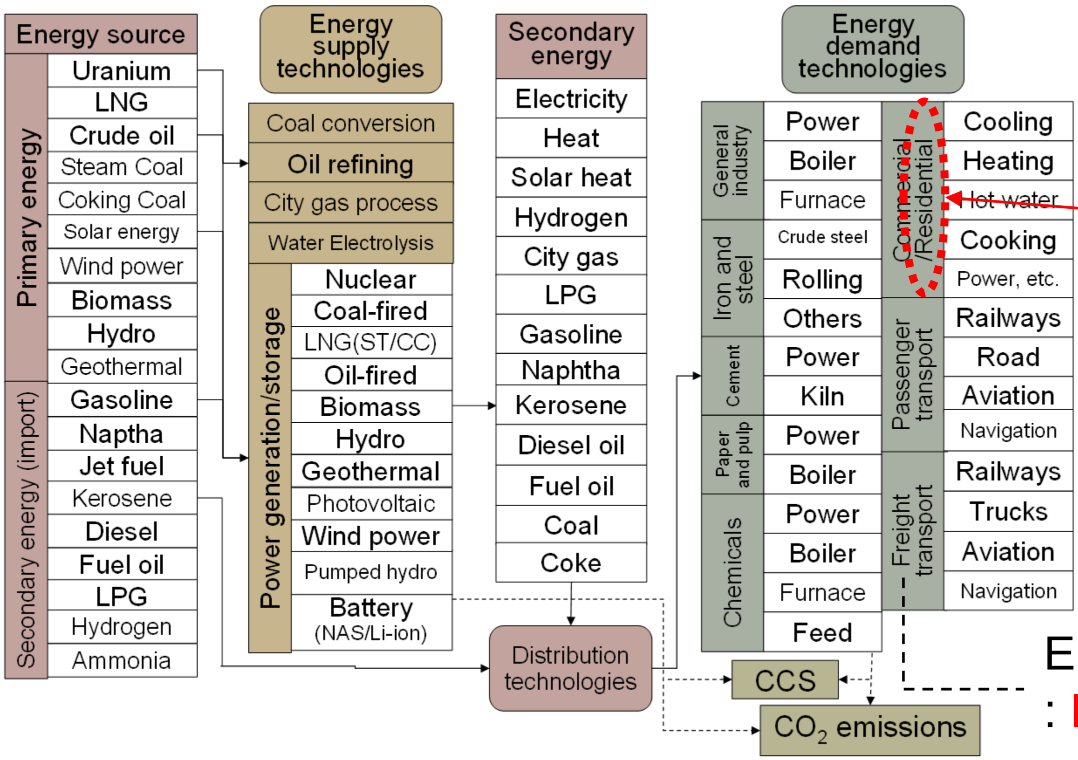
2.1 Bottom-up technology selection model

- It is a large-scale linear programming model with the objective function of minimizing the total energy system cost.
- It can quantitatively evaluate the consumption dynamics, energy consumption, and CO2 emissions of each energy consumption technology.
- In this study, we newly added wheeling charge to the objective function.



Energy service demand
: Exogenous variables

Fig.6 Model overview diagram

- The residential sector will be divided into 100 categories.
- Energy service demand will be recombined into electricity demand and hot water demand.

2.2 Objective function and Constraint

【 objective function 】

$$
\begin{aligned}
&minimize\ ATC \\
&= \sum_k \left(AnnualizedInvcost_k \cdot INV_k + Fixom_k \cdot CAP_k + Varom_k \cdot ACT_k\right) \\
&+ \sum_e (Importprice_e \cdot IMP_e) + \sum_e (Domprodcost_e \cdot DOMPR_e) \\
&+ \sum_l (Wfb \cdot V_l + Wvb \cdot WB_l) \qquad \cdots (1)
\end{aligned}
$$

Objective function = (capital investment cost + fixed cost of equipment + variable cost of equipment) + (fuel import cost) + (domestic fuel production cost) + (wheeling charge)

【 constraint 】

- **Common constraints on energy technologies: Equations (2)-(4) are valid for installed capacity and operating volume.**

$$CAP_k = resid_k + INV_k \qquad \cdots (2) \qquad\qquad CAP_k \cdot cf_k \geq ACT_k \qquad \cdots (3)$$

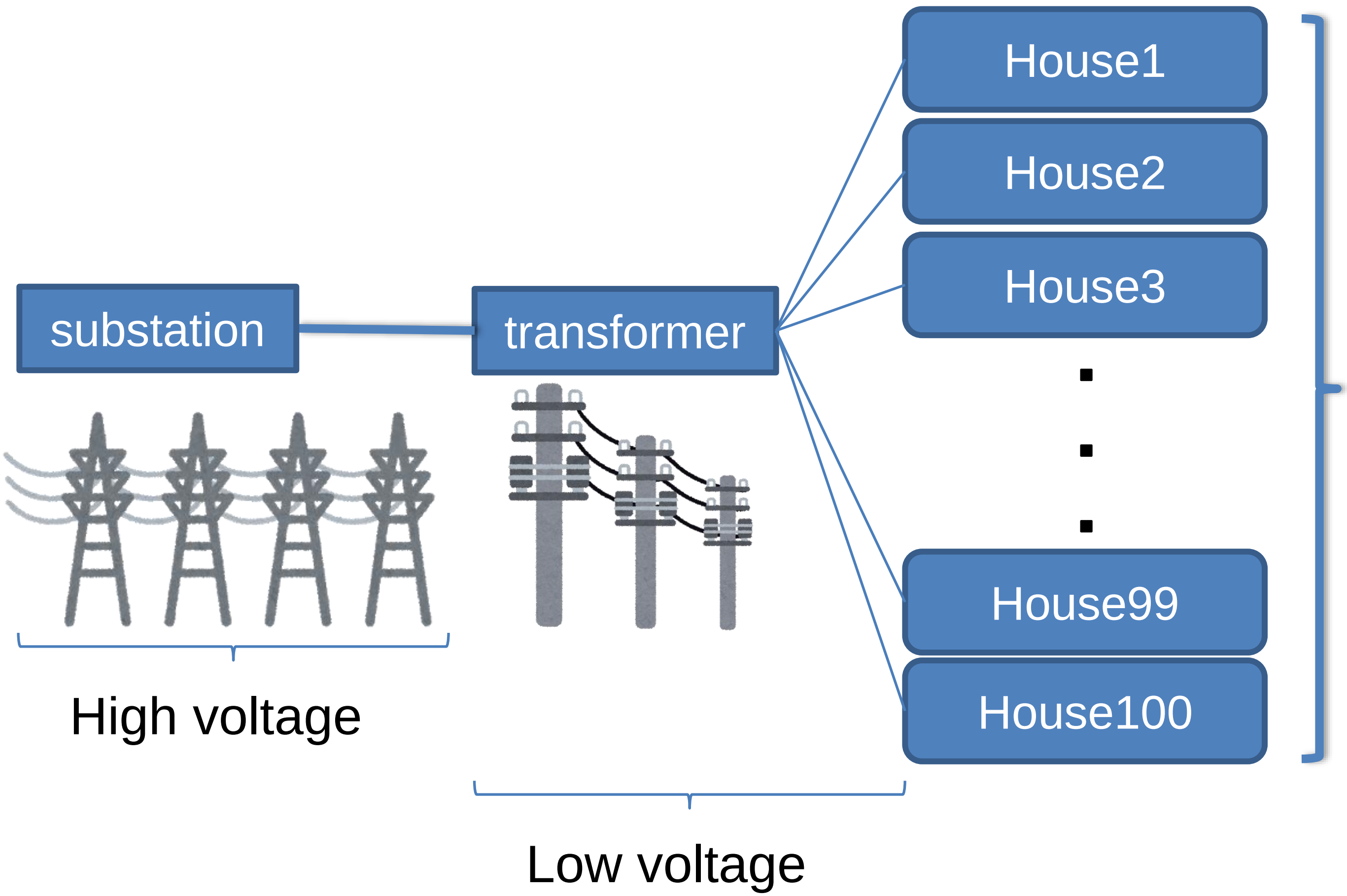
$$\sum_k dmx_{(k,d')} \cdot ACT_k \geq dem_{d'} \qquad \cdots (4)$$

- **Energy Supply and Demand Balance Formula**

$$\sum_k \left(output_{k,e} \cdot ACT_k\right) + IMP_e + DOMPR_e \geq \sum_k (input_k \cdot ACT_k) \qquad \cdots (5)$$

The supply-demand balance equation in Equation (5) holds for all energy sources and energy carriers.

2.3 Detailing the household sector



- Power demand varies by household
- PV generation pattern are the same for all households

In this simulation, I calculate the optimal capacity of power transmission and distribution equipment in each voltage band.

2.4 Residential DAC and CCU systems

- Households that can perform DAC and CCU in the household sector will be as follows.
- Capacity of DAC, CCU, and PV equipment will be optimized.

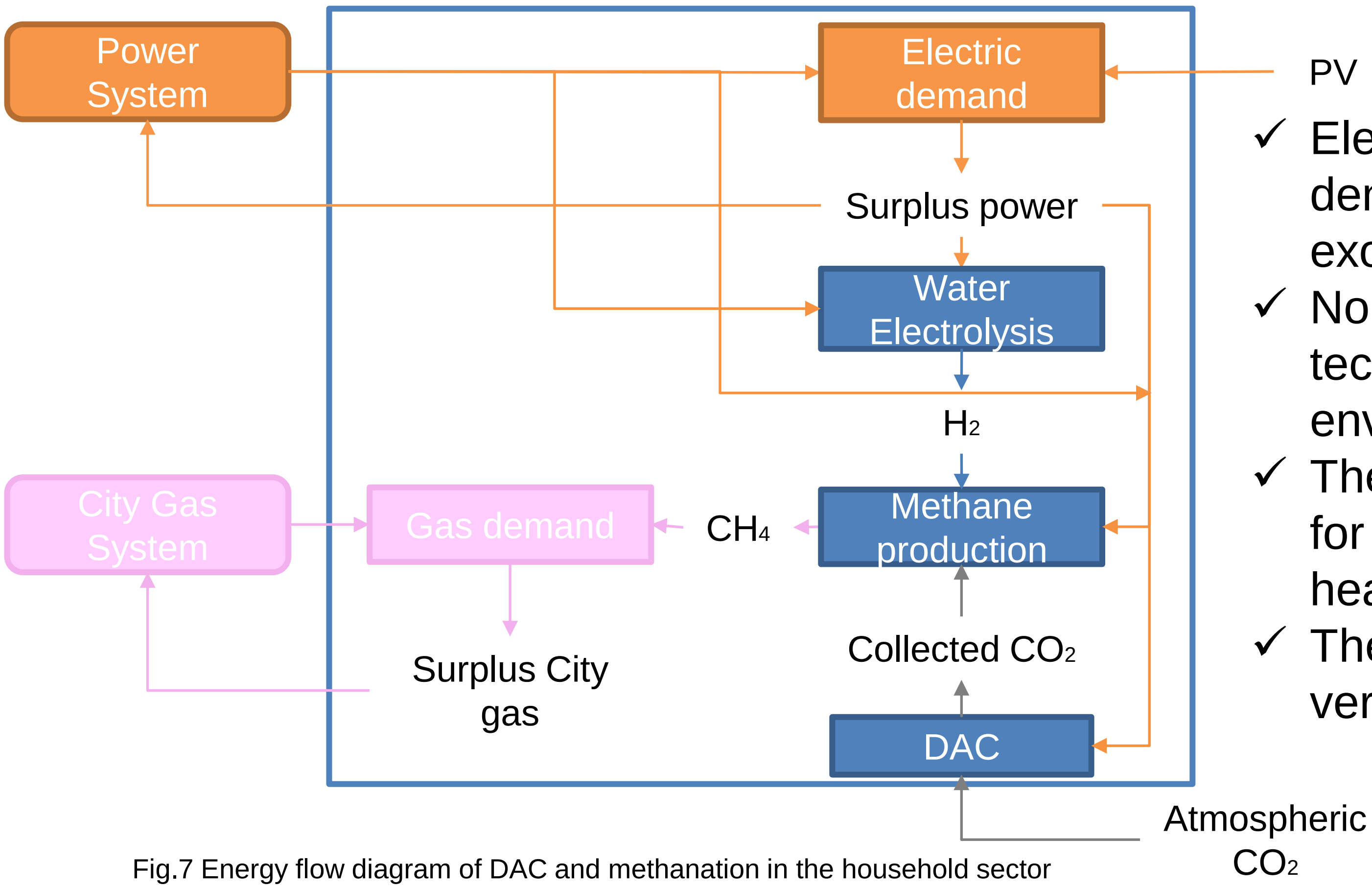
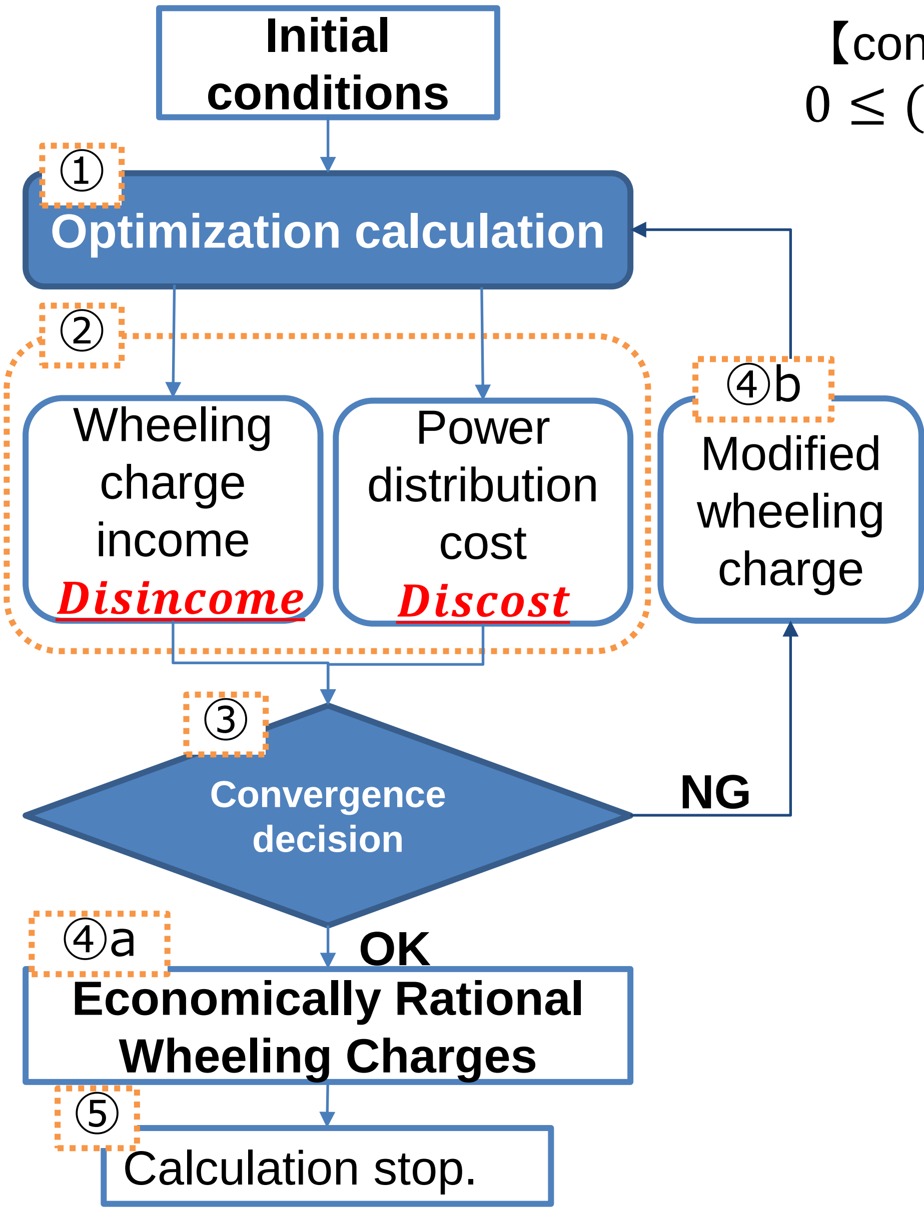


Fig.7 Energy flow diagram of DAC and methanation in the household sector

- ✓ Electricity and gas demand is given exogenously.
- ✓ No energy storage technology is envisioned.
- ✓ The heat required for the DAC is the heat of methanation.
- ✓ The cost of DAC is very low.

2.5 Derivation of wheeling charges by repeated calculation



【convergence decision】

$$0 \leq (Disincome - Discost)/Discost \leq 0.05 \quad \cdots (6)$$

① Perform N times optimization calculations.

② The optimization calculation results in ***Disincome*** (Wheeling charge income) and ***Discost*** (Power distribution cost).

③ Convergence decision is made as shown in equation (6)

④ a N times' Wheeling charge is Economically Rational Wheeling Charges

b Modify wheeling charge based on ***Discost*** of N times and Give to the N+1th optimization calculation as a new wheeling charge

⑤ Calculation stop.

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    3. Electricity Supply and Demand Dynamics of Household DACs
    4. CO2 Emissions and Absorption

4. Discussion/Conclusion

3.0 Profit at current consignment rates

Table1：Current Wheeling charge System

	Current Wheeling charge System
Basic rate	25.74[$/kW/year]
Metered rate	0.0745[$/kWh]

Table2：Balance in optimization calculation

	[bill. $/year]
Wheeling charge revenue	6.91
Power transmission and distribution costs	7.67

Deficit of 760 million dollar

Table3：Modification of wheeling charge by repeated calculation

	Current (ref case)	Modified(BAU case)
Basic rate	25.74[$/kW/year]	39.60[$/kW/year]
Metered rate	0.0745[$/kWh]	0.0797[$/kWh]

A significant increase in the unit price of wheeling charges will be necessary.

3.1 Calculation Conditions & Case setting

【Power rerated components subject case (FIX)】

- As shown in the figure on the right, the breakdown of transmission and distribution costs is 80% fixed costs and 20% variable costs.
- Currently, the cost is recovered mainly through metered rates. This is thought to cause a problem.
- I will raise the recovery ratio in power rerated to 80% and calculate the recovery ratio in energy rerated as 20%.

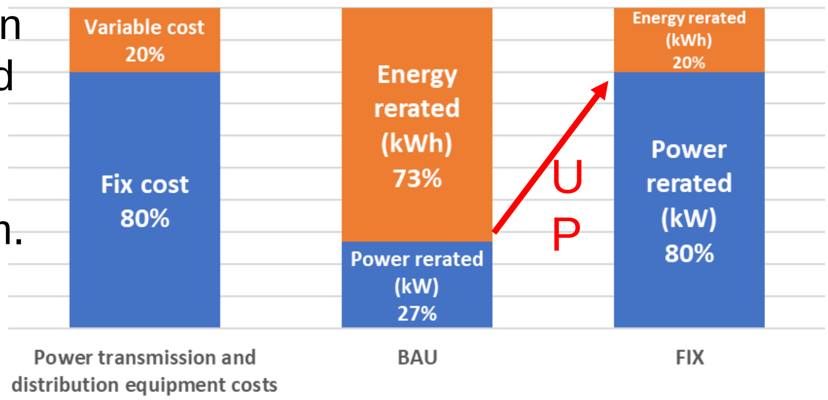

Figure 9: Image of the FIX case

【Partial generation side billing case(CFS)】

- As shown in the figure on the right, the maximum transmission power is higher for reverse power than for forward power in PV installation households.
- However, in the current situation, the forward tide is used as the contracted power.
- This increase will require new investment, which in turn will require an increase in the wheeling charge.
- In consideration of this point, the contracted power for the power rerated is set to the maximum value for forward and reverse tide.

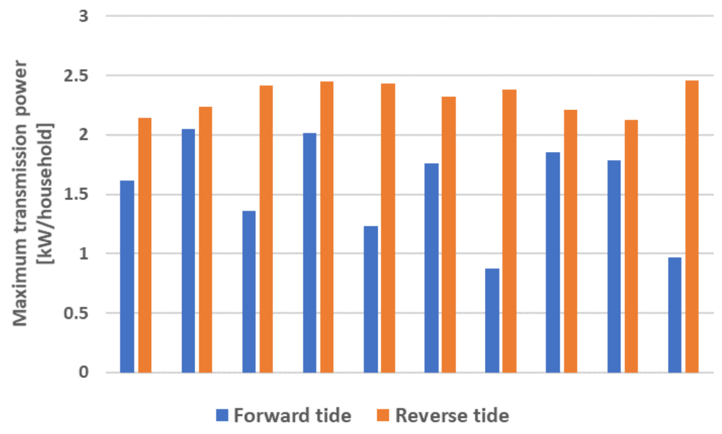

Figure 10 Comparison of forward and reverse tides of maximum transmission power for households with PV installed in BAU case

3.1Calculation Conditions & Case setting

Table4 Kind of case

Kind of case	Repeated calculation	Partial generation side billing	Power rerated components subject case
ref case	—	—	—
BAU case	○	—	—
CFS case	○	○	—
FIX case	○	—	○
CFS&FIX case	○	○	○

【Year/Area/CO2】

Year	**2050**
Area	**Tokyo Metropolitan Area**
CO2	**Net zero**

Table5 Kind of household

Kind of household	PV	DAC & Methanation	Kind of hot water instrument	Electricity demand	Ratio
PV&HP	○	×	Heat pump water heaters	Middle	10%
PV	○	×	Electric heating water heater	High	30%
PV&DAC	○	○	Gas water heater	Middle	10%
HP	×	○	Heat pump water heaters	Middle	10%
Normal	×	×	Gas water heater	Low	40%

3.2 Effect of changing wheeling charges

【Cost Burden Disparity Problem of Wheeling Charges】

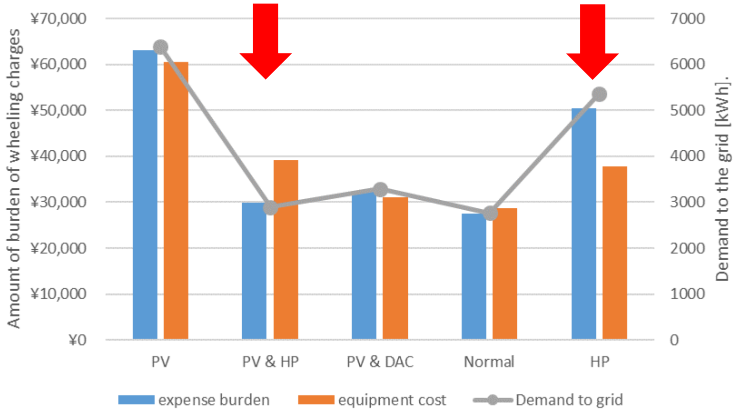

Fig.11 Amount of burden of wheeling charge in BAU

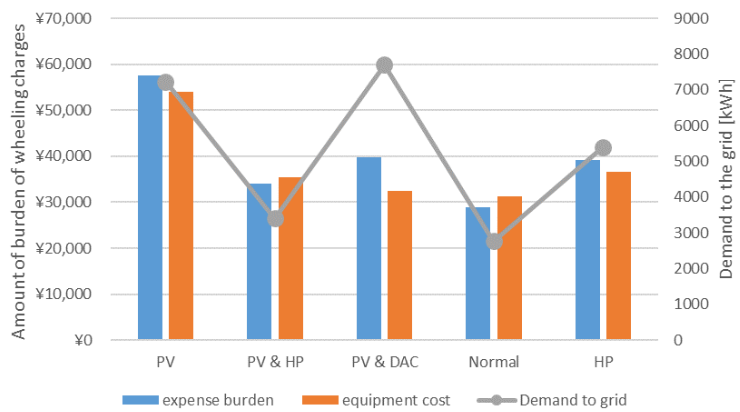

Fig.12 Amount of burden of wheeling charge in CFS&FIX

- The figure on the left shows a comparison of the cost burden and equipment cost for each household in the BAU case.
- In the BAU case, households that use more electricity from the grid tend to bear more of the cost burden. Therefore, we can see that there is a cost burden gap between HP and PV & HP households.
- This cost-sharing disparity has been best eliminated in the FIX&CFS case (left). In this case, the cost burden disparity problem has been solved by changing the contracted power, which is mainly a basic charge.
- The difference in grid electricity demand between PV&DAC households is due to the change in the amount of DAC and methanation technology installed.

3.2 Effect of changing wheeling charges

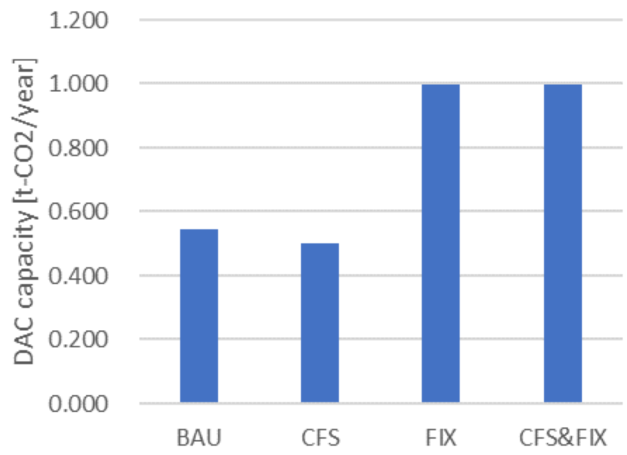

Fig.13 Average capacity of residential DAC in each case

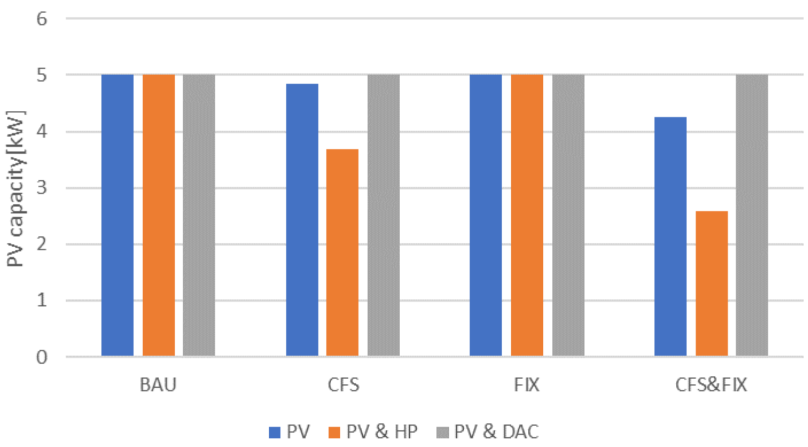

Fig.14 Average capacity of residential PV in each households in each case

- ✓ By changing to FIX case, the capacity of DAC will increase.
- ✓ The introduction of partial generation side billing system has the effect of reducing the amount of PV installed in some households.

Although the cost burden disparity problem can be solved by changing the transmission rate system, it may inhibit the introduction of residential PV.

3.3 Electricity Supply and Demand Dynamics of Household DACs

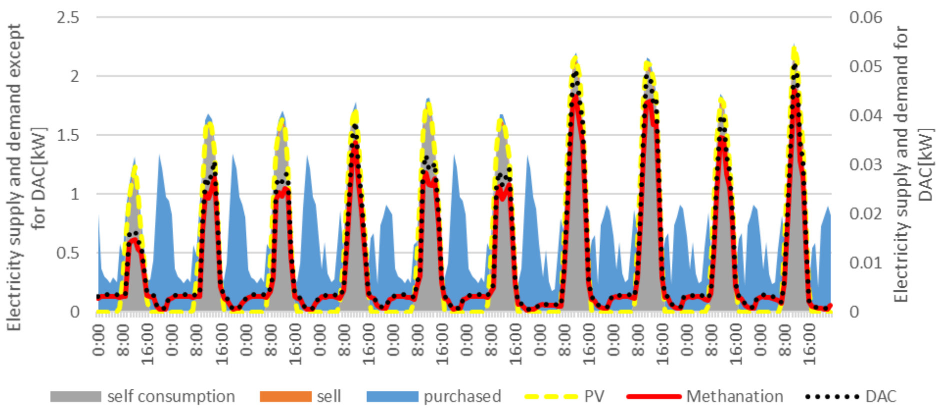

Fig.15 Electricity Supply and Demand Dynamics in BAU

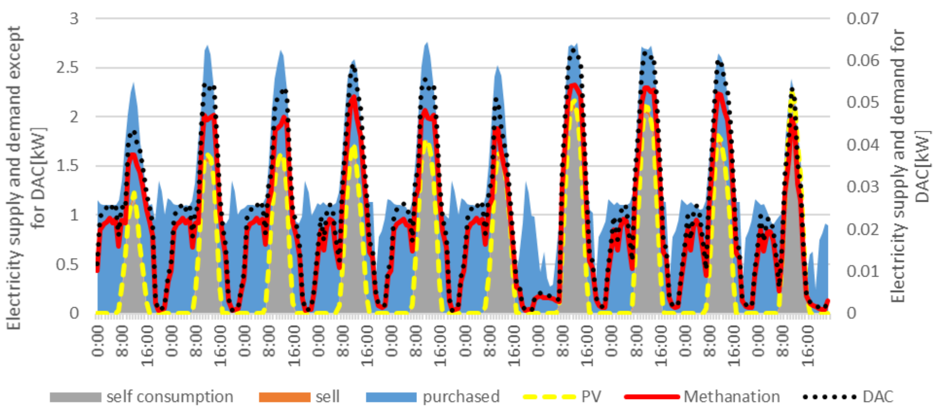

Fig.16 Electricity Supply and Demand Dynamics in FIX & CFS

- Comparing the results in the left figure, in the BAU case, the methanation and DAC are only operating during the time when the PV is generating electricity.
- On the other hand, in the FIX&CFS case, the methanation is operating even at night.
- This can be attributed to the fact that the electricity price per kWh has become cheaper since the feed-in tariff, which used to be mainly a metered rate, has become mainly a basic rate.

3.4 CO2 Emissions and Absorption

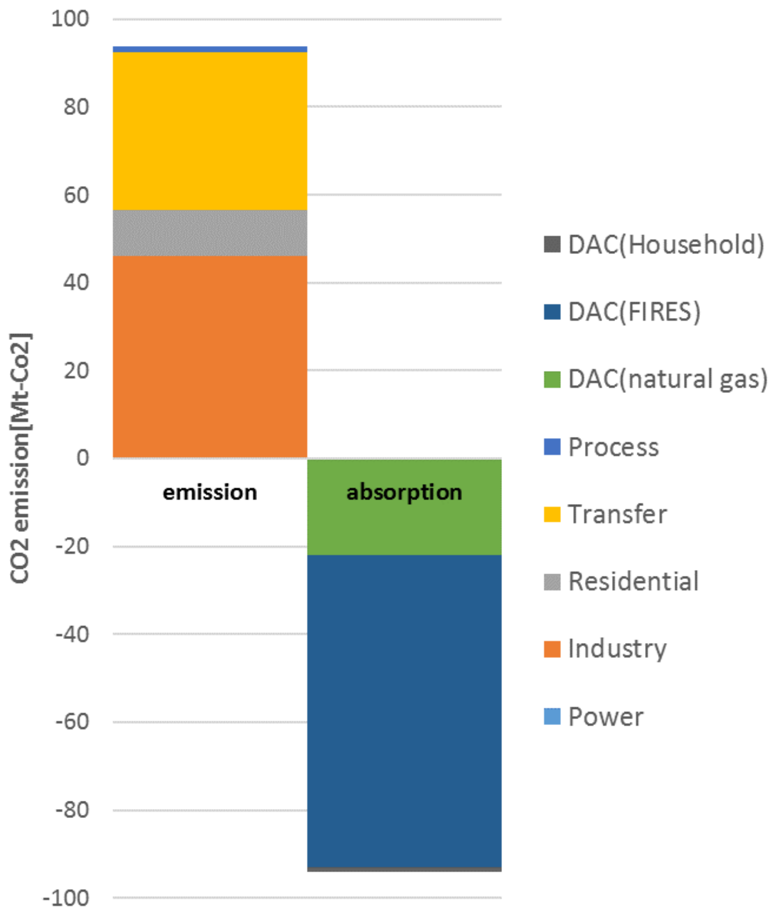

Fig17. CO2 Emission and Absorption in BAU

- The figure on the left shows the amount of CO2 emitted and absorbed by each sector in the BAU case.
- Most of the CO2 emissions in the net zero case are accounted for by the industrial and transportation sectors.
- In the power generation sector, zero emissions are achieved.
- The change in the feed-in tariff had little effect on CO2 emissions.
- In addition, the degree of contribution of DAC in the residential sector to negative emissions was negligible.

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Conclusion/Future Work

Conclusion

・We have developed a model based on the technology selection model that can evaluate wheeling charge and negative emission technologies.

・Under the current wheeling charge system, it was found that the cost burden disparity problem will occur along with the increase in wheeling charge. In order to solve this problem, it is necessary to change the wheeling charge system.

・Under the CO_2 emission constraint, negative emission technologies in the household sector will be introduced, but their contribution to the overall energy system will be small.

Future Work

・Expand the target area to all of Japan.

・Consider other future technologies and services.

Thank you for listening !!

Acknowledgment
This work was supported by JSPS KAKENHI Grant Number 20H02679

2.5 Derivation of wheeling charges by repeated calculation

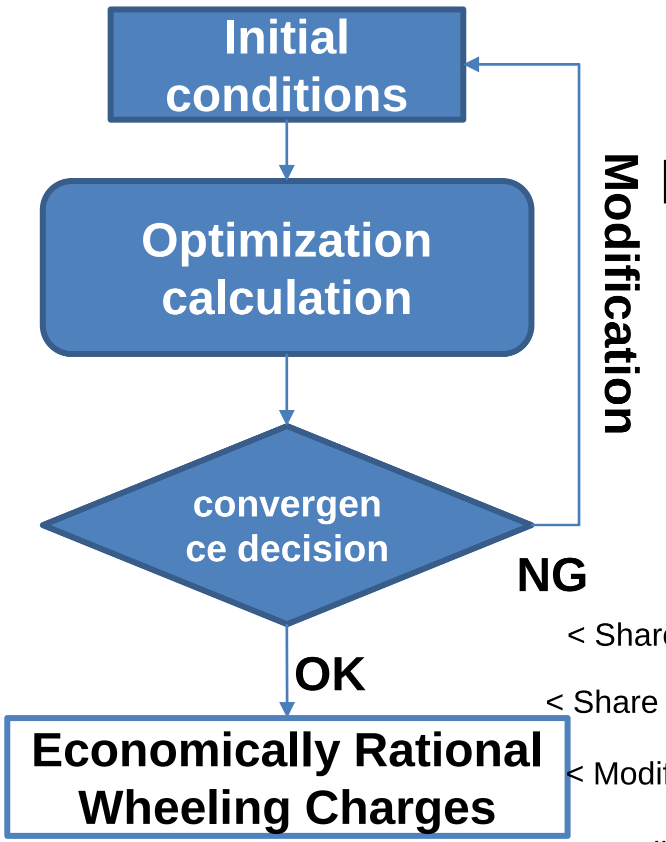

Fig. 8 Schematic diagram of the calculation of wheeling charge by iterative calculation

【convergence decision】

$$0 \leq (Disincome - Discost)/Discost \leq 0.05 \quad \cdots (6)$$

【 Modification of wheeling charge 】

① Exogenously divide the transmission and distribution cost obtained from the optimization calculation into the basic rate recovery portion and the metered rate recovery portion.

② The unit cost of each of the basic rate recovery and metered rate recovery will be derived from the total maximum consigned electricity and the amount of consigned electricity.

③ The modified unit price of the wheeling charge is obtained as shown in Equations (9) and (10).

< Share of basic charge > $$FIXcost = DIScost \cdot Ratio\_fix \quad \cdots (7)$$

< Share of metered rate > $$VARcost = DIScost \cdot (1 - Ratio\_fix) \quad \cdots (8)$$

< Modified base rate > $$Wfb1 = FIXcost/V \times 0.1 + Wfb \times 0.9 \quad \cdots (9)$$

<Modified metered rate> $$Wvb1 = VARcost/Wb \times 0.1 + Wvb \times 0.9 \quad \cdots (10)$$

< Total maximum consigned power > $$V = \sum_{i1} v_{i1} + \sum_{i2} v_{i2} + \sum_{j1} v'_{j1} + \sum_{j2} v'_{j2} \quad \cdots (11)$$

< Total amount of electricity delivered > $$Wb = \sum_{i1} wb_{i1} + \sum_{i2} wb_{i2} + \sum_{j1} wb_{j1} + \sum_{j2} wb_{j2} \quad \cdots (12)$$