Electronic Supplementary Material
(Online Resource 1)

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1.1 Computational model structure for Greenhouse Gas (GHG) emission estimation

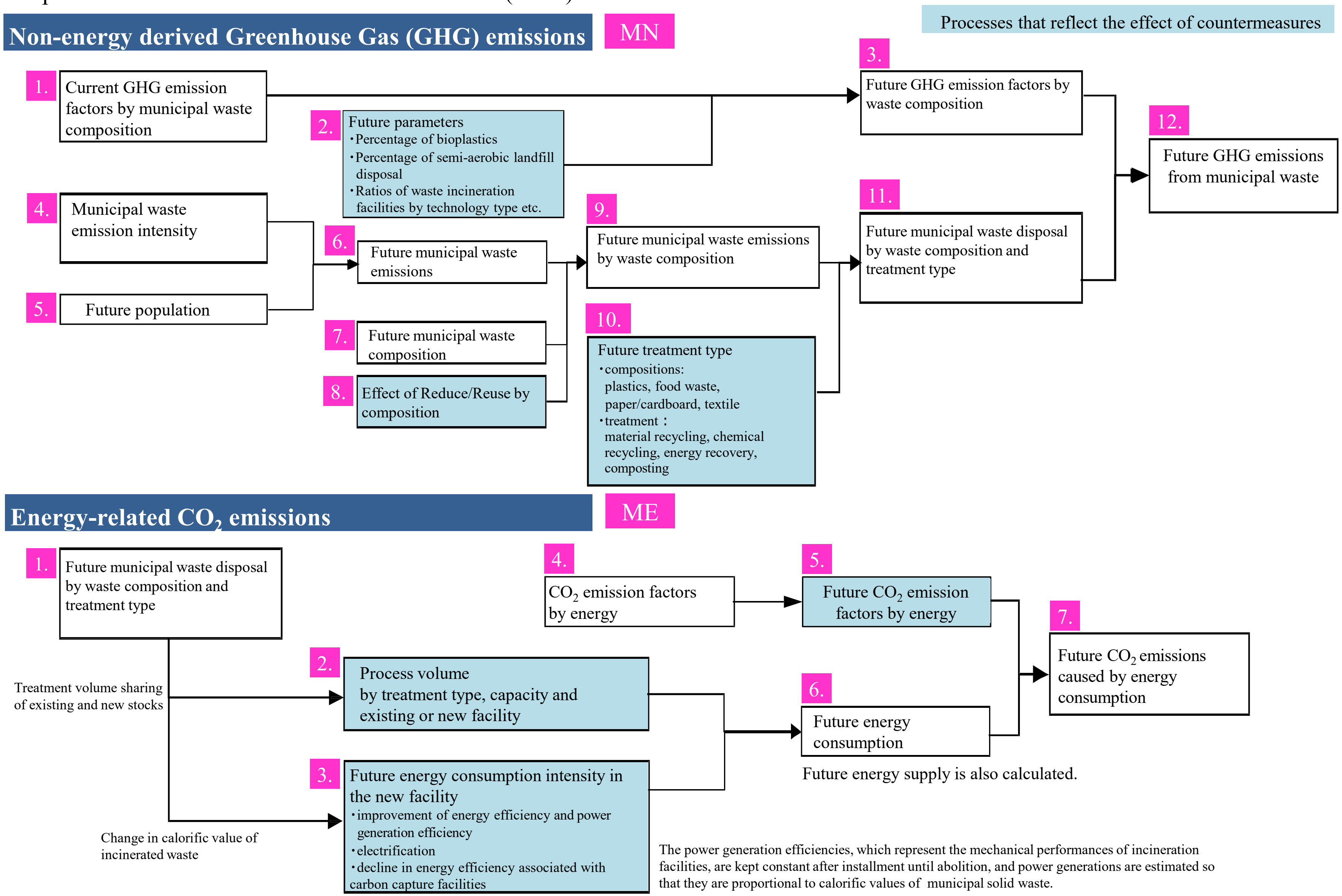

Fig. ESM1 Structure of the computational model for estimating the future GHG emission (municipal waste)

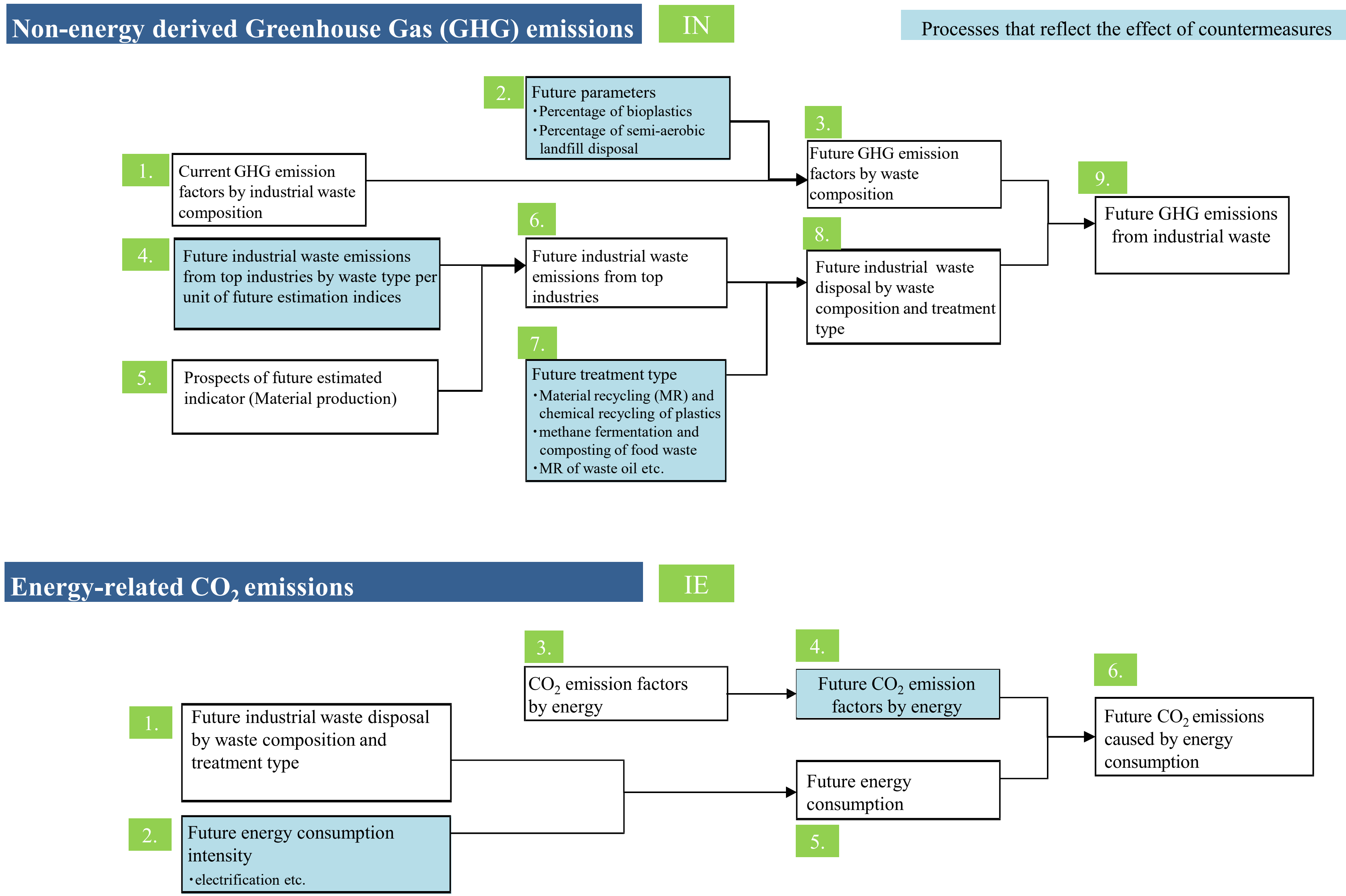

Fig. ESM2 Structure of the computational model for estimating the future GHG emission (industrial waste)

1.2 Summary of emission quantification parameters

Table ESM1 Premises in each case: Priority Area I

Scenarios	Priority Area I (Decarbonization of the entire life cycle of materials via material cycles)					
	Waste plastics	Waste oil	Wastepaper	Disposable diapers	Synthetic fiber scraps	Scrap tires
Planning Expanded Planning	• Charging for plastic bags. • Reductions based on the Voluntary Action Plan by the Liaison Committee of Associations Promoting 3Rs. • Adopting bioplastics (approximately 2 million tons by 2030*). • Material recycling (MR) and circular chemical recycling (CR) based on the Japan Chemical Industry Association's Future Vision (circular CR yield: 70% by 2050). • Extermination of landfills and incineration without energy recovery by 2035.	• MR of incinerated waste solvents (30% by 2030).				
Innovation	• Circular CR yield (80% by 2050) • Adopting 2.5 million tons of bioplastics by 2050*	• MR of waste oil converted into fuels (80% by 2050). • MR of waste oil consumed (30% by 2050).	• MR (60% by 2050).	• MR (10% by 2050) • Biomaterial conversion (100% by 2050).	• MR (30% by 2050). • Feedstock recycling (10% by 2050).	• Retreading (10% by 2050). • Feedstock recycling (18% by 2050). • Conversion of petroleum components into biomass (34% by 2050).

Advanced Innovation Net Zero Emissions Maximum Actions	• Circular CR recycling yield (90% by 2050). • Adopting 2.5 million tons of bioplastics by 2050* (achieving 100% biomass by 2045). • 25% reduction**	• MR of waste oil burned (50% by 2050). • Biomass conversion of oil to be burned (100,000 tons by 2050).	• Reduction (20% by 2050, municipal waste). • MR (75% by 2050).	• MR (20% by 2050).	• Feedstock recycling (20% by 2050).	• Retreading (20% by 2050). • Feedstock recycling (20% by 2050). • Conversion of petroleum components into biomass (44% by 2050).

*Based on its CO_2 reduction effect (2.09 million tons), which is indicated in the national Climate Action Plan, the 2030 target for adopting bioplastics (approximately 2 million tons) suggests a biomass ratio of 30%–40%. The 2050 target (2.5 million tons) expects all plastics to be bio-based.

**25% decrease in waste plastics was anticipated based on the aggregation of probable reduction possibilities for waste plastics by each plastic product.

Table ESM2 Premises in each case: Priority Area II

<table>
<tr><th rowspan="3">Scenario</th><th colspan="4">Priority Area II (Development of waste management systems contributing to regional decarbonization)</th></tr>
<tr><th colspan="3">Organic-waste management</th><th rowspan="2">Advanced waste energy utilization and carbon capture, utilization and storage (CCUS)</th></tr>
<tr><th>(Food loss reduction)</th><th>(Landfill diversion)</th><th>(Methane fermentation, etc.)</th></tr>
<tr><td>Planning</td><td rowspan="6">The amount of food loss generated (municipal waste and industrial waste) will be halved by FY2030 compared to FY2000 levels.</td><td rowspan="2">Non-incineration landfill (raw waste landfill) of organic municipal and organic industrial waste (animal and plant residues, paper, natural fiber, wood waste, and livestock manure) will be reduced to zero by FY2035.
The percentage of semi-aerobic landfill volume will reach 77% in FY2030 for the final disposal of municipal waste and 76% for the final disposal of industrial waste.</td><td></td><td></td></tr>
<tr><td>Expanded planning</td><td colspan="2">New incineration facilities will be limited to those with a capacity of 100 tons/day or higher in the 2030s and beyond. Those with lower capacities will adopt methane fermentation and other technologies or transfer their waste to high-capacity facilities.</td></tr>
<tr><td>Innovation</td><td>Raw waste landfills of organic and sewage sludge from the manufacturing sector in organic industrial waste is estimated to be reduced to zero by FY2035.</td><td colspan="2">New incineration facilities will be limited only to those with a capacity of 300 tons/day or higher in the 2030s and beyond; moreover, newly built (or upgraded) facilities will adopt methane fermentation as well.
Facilities that supply steam externally to meet industrial heat demand will also be built at a pace of about one per year.</td></tr>
<tr><td>Advanced Innovation</td><td rowspan="3">Raw waste landfills of waterworks sludge among organic industrial waste will be reduced to zero by FY2035.</td><td colspan="2">Same as above.</td></tr>
<tr><td>Net Zero Emissions</td><td colspan="2">CCUS will be employed to achieve net zero emissions (assuming that it will start in the 2040s, with a recovery target of 90%).
*Same as the Advanced Innovation scenario for other measures.</td></tr>
<tr><td>Maximum Actions</td><td colspan="2">CCUS for all exhaust gases will be deployed at all facilities (including existing facilities) (assuming that it will start in the 2040s, with a recovery target of 90%).
*Same as the Advanced Innovation scenario for other measures.</td></tr>
</table>

*Table ESM2 describes municipal waste management systems. For industrial waste management, no scenarios were developed for methane fermentation, advanced energy utilization, or CCUS.

Table ESM3 Premises in each case: Priority Area III

<table>
<tr><th rowspan="3">Scenario</th><th colspan="4">Priority Area III (Decarbonization of waste treatment facilities and vehicles)</th></tr>
<tr><th colspan="3">Municipal waste treatment facilities, vehicles, etc.*1</th><th rowspan="2">Industrial waste treatment facilities, vehicles, etc.</th></tr>
<tr><th>Decarbonization of incineration facilities</th><th>Decarbonization of human waste treatment facilities</th><th>Decarbonization of other facilities and vehicles</th></tr>
<tr><td>Business as Usual</td><td rowspan="2">New facilities will have:
• The power generation efficiency required to receive the current subsidies for promoting a circular society
• The same level of electricity and fuel consumption rates as existing facilities.</td><td rowspan="3">New facilities will have the same level of electricity and fuel consumption rates as existing facilities.</td><td></td><td></td></tr>
<tr><td rowspan="2">Planning</td><td rowspan="2">All collection vehicles will be replaced with electric vehicles (EVs).
(EVs will linearly increase until 2050)</td><td rowspan="2">All facilities that incinerate waste plastics will recover energy by FY2035.
Sewage sludge incineration facilities will reach 100% of high-temperature incineration by FY2030.
As for sewage sludge incineration facilities, two new types of furnaces and two sewage sludge fuel conversion furnaces will be added every year until FY2030.</td></tr>
<tr><td>All municipal waste incineration facilities will recover energy by FY2035. *2</td></tr>
<tr><td>Expanded Planning</td><td>New facilities will improve power generation efficiency through higher boiler steam temperatures and pressure (6MPa, 450°C).
Energy saving within facilities</td><td>New facilities will use no fuels (dehydrating and transporting human waste to incineration facilities for treatment).</td><td>Methane fermentation: new facilities will improve the energy balance including larger scales.</td><td>All industrial waste collection vehicles will be replaced with EVs by FY2040. CO_2 emission factors for electricity will reach zero by FY2050.</td></tr>
<tr><td>Innovation</td><td>New facilities will significantly reduce the use of combustion-enhancing fuel additive startup (in addition to the above measures for the expanded planning scenario).</td><td>New facilities will combine food waste treatment to use no fuels and significantly reduce electricity consumption.</td><td>Residue transport (possibly 10-ton) vehicles in addition to the above vehicles will be replaced with EVs.</td><td>Same as above.</td></tr>
<tr><td>Advanced Innovation</td><td colspan="3">All fuels used at municipal waste treatment facilities (including heavy machinery at final disposal sites) will be replaced with biomass fuels by FY2050.
(Same as the innovation scenario for other measures).</td><td>All fuels used at industrial waste treatment facilities (including heavy machinery at final disposal sites) will be replaced with biomass fuels by FY2050.</td></tr>
<tr><td>Net Zero Emissions</td><td colspan="3">Same as above.</td><td>Same as above</td></tr>
<tr><td>Maximum Actions</td><td colspan="3">Same as above.</td><td>Same as above.</td></tr>
</table>

*1 The performance levels of the new facilities in all scenarios will be the same as those in the BAU and planning scenarios until 2030. Facilities starting operations in 2031 or later will have different performance levels according to each scenario.

*2 Same as the other scenarios mentioned below, including the expanded planning scenario.

2. Results and discussion

2.1 Estimated GHG emission by scenario in 2050

Table ESM4 GHG emission projections by scenario and source in 2050

($ktCO_2$)		Scenario					
		BAU	Expanded planning	Innovation	Advanced innovation	Net zero emissions	Maximum measure
Emission source	Landfill	1,350	898	851	834	834	834
	Bioprocessing	377	377	377	377	377	377
	Incineration	11,172	4,299	3,167	2,126	2,126	2,126
	Raw fuel use	16,703	14,696	4,636	2,827	2,827	2,827
	Energy-related CO_2	4,367	1,911	1,468	0	0	0
	CCUS※	0	0	0	0	−6,164	−16,138
	Total	33,968	22,180	10,499	6,164	0	−9,975

*The estimates are calculated considering the reduction effects of CCS for CO_2 in exhaust gas

2.2 Current GHG emission sources from waste plastics and waste oils

Incineration and energy use of waste plastics produces approximately 14.7 million t-CO_2. Approximately 6.8 million t-CO_2 (about 46%) and 7.4 million t-CO_2 (about 50%) of CO_2 were from municipal and industrial waste, respectively. Both in municipal and industrial waste, the largest emission sources of CO_2 are associated with incineration (including incineration with power generation and heat utilization).

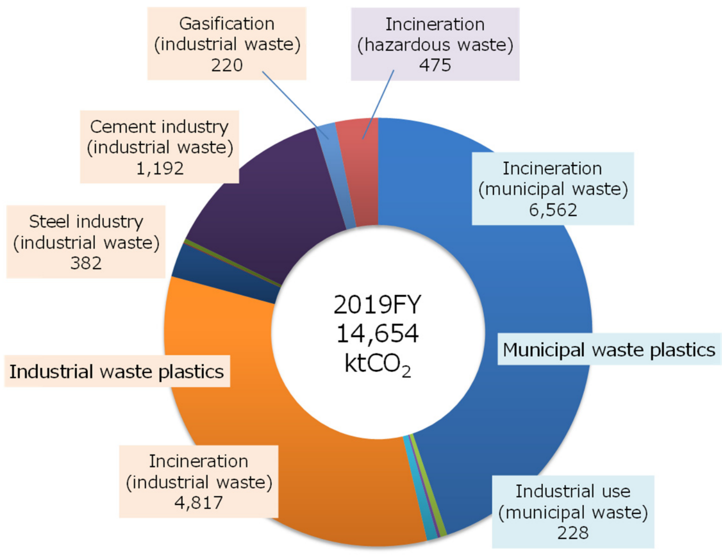

Fig. ESM3 Information on CO_2 emissions from incineration and energy use of waste plastics in 2019 (unit: $ktCO_2$)

CO_2 emission from the incineration of waste oil is approximately 10 million t-CO_2 since the late 2000s. “Fuel use” (use of waste lubricants as recycled heavy oil or use of waste solvents as fuel) accounted for over half of the emissions in FY2019. These activities contribute to the reduction of CO_2 emissions from heavy oil and fuel oil at factories, etc. However, as efforts to achieve net zero emissions by 2050, the use of waste oil as fuel, which generates fossil CO_2, is expected to decline.

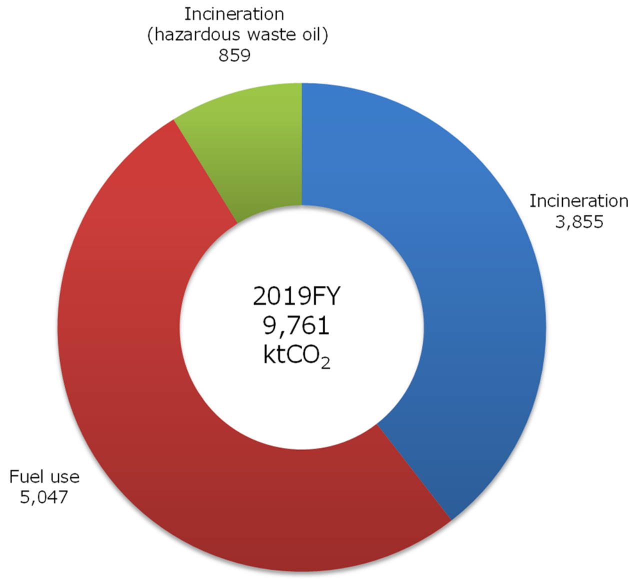

Fig. ESM4 Information regarding the CO_2 emissions from incineration and energy use of waste oil in 2019 (unit: $ktCO_2$)