

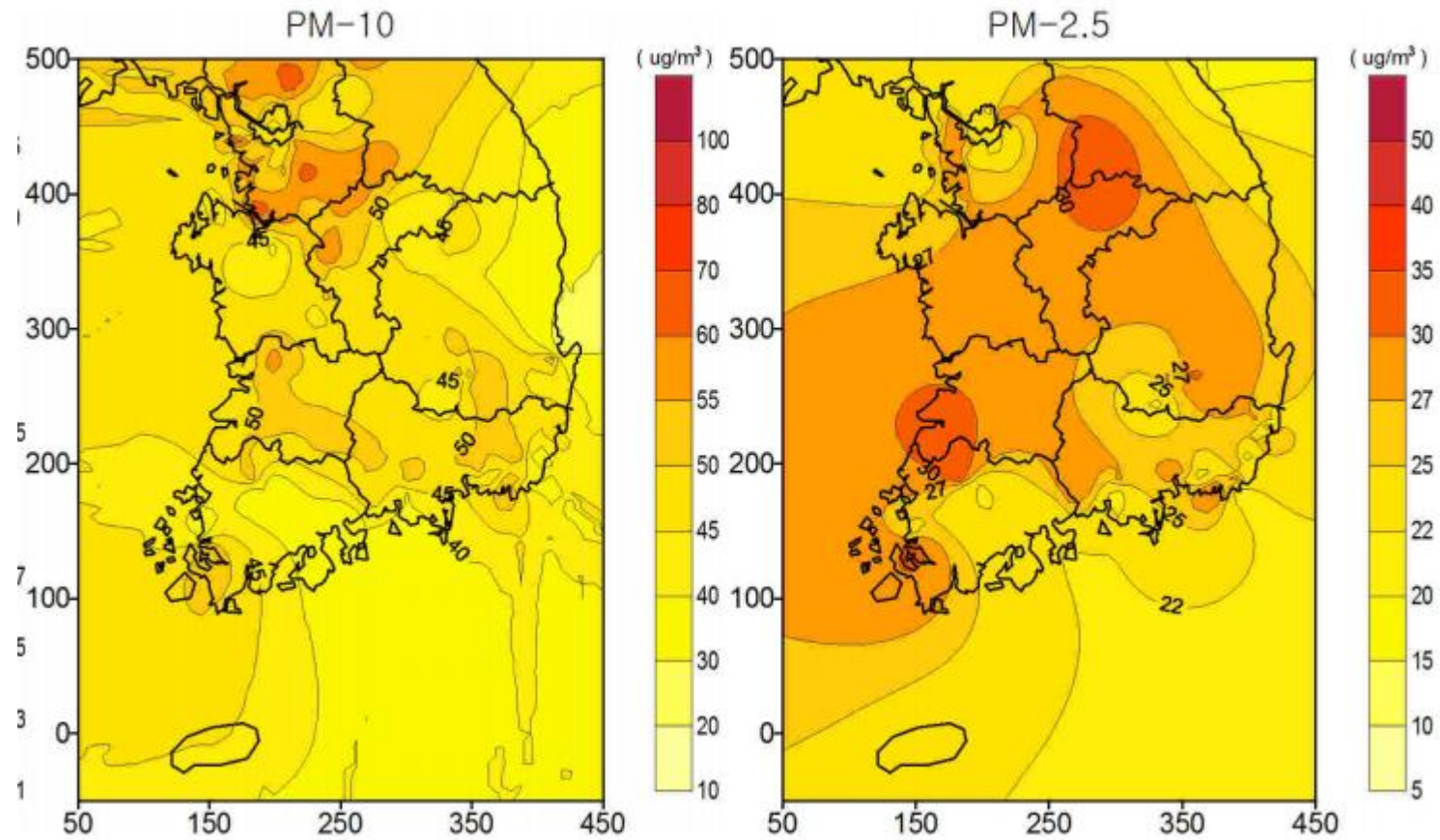
# **Fine Dust Management in Korea**

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**Korea University**

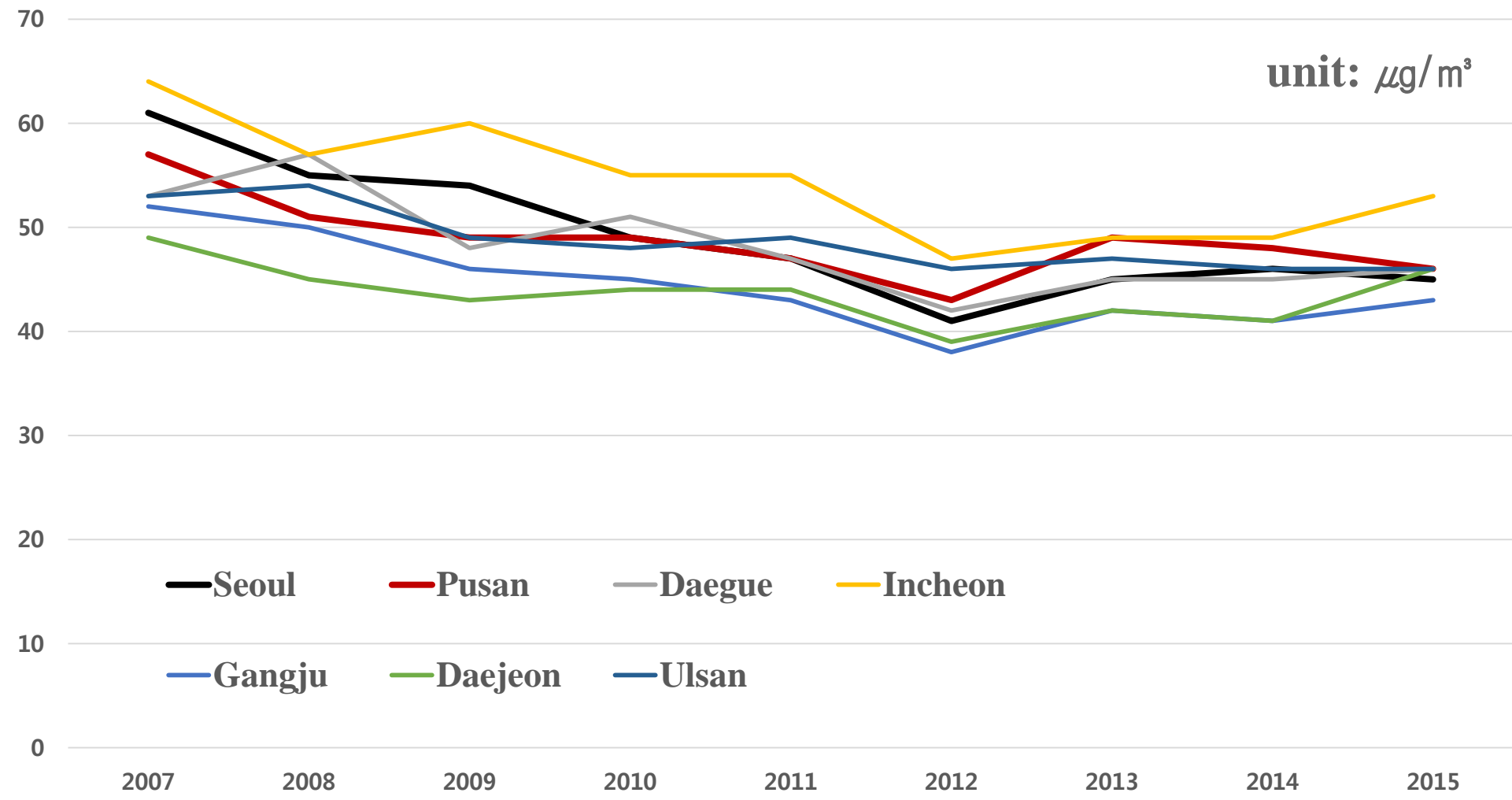
**yscho@korea.a.c.kr**

# Annual average of Fine Dust concentration (2015)

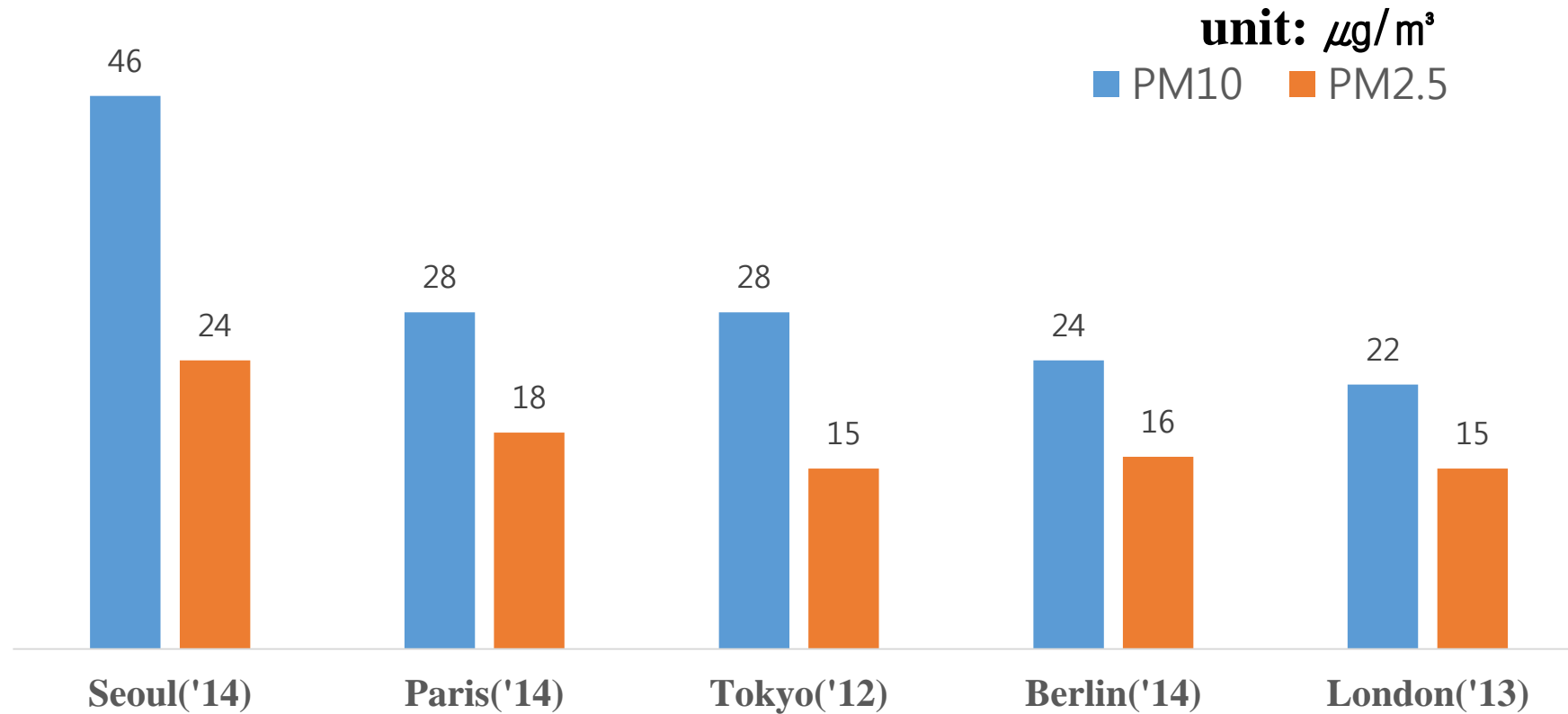


Source: National Institute of Environmental Research (2016), Annual report of air quality in Korea 2015.

# PM<sub>10</sub> concentration trend of major cities in Korea



# Comparison with major cities



Source: WHO, Global Urban Ambient Air Pollution Database, 2016.

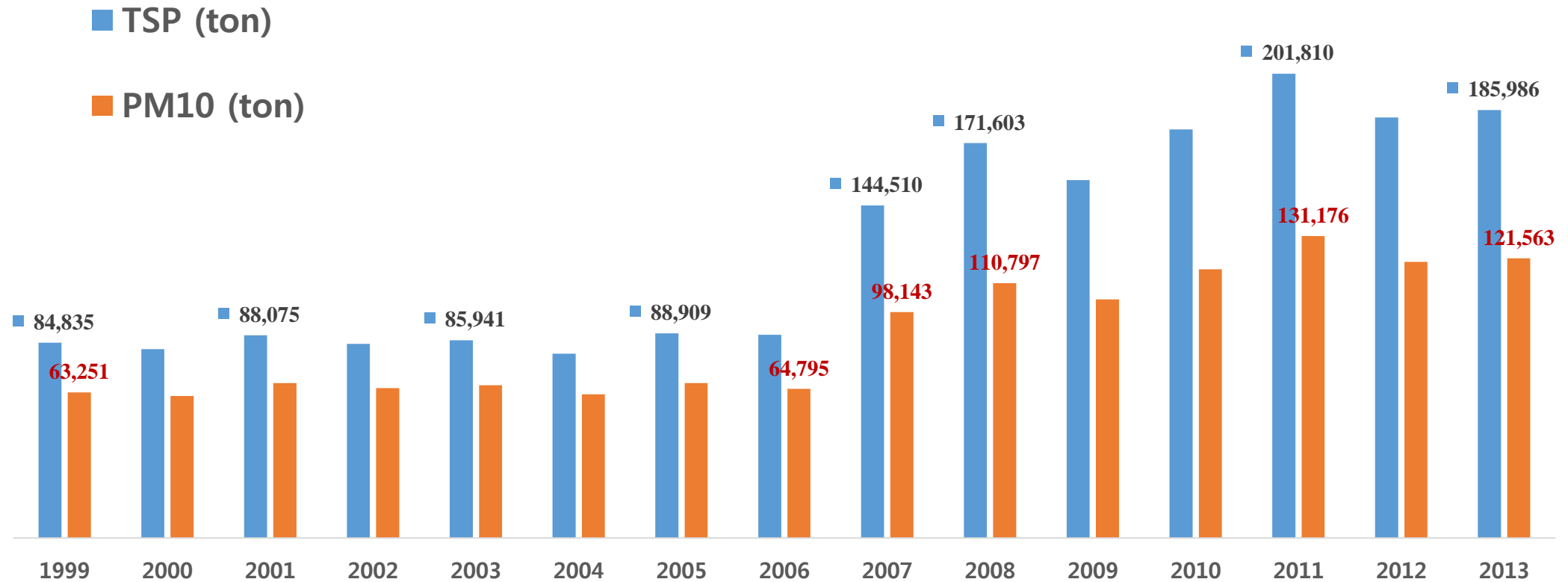
# Changes in environmental standards in Korea

unit: $\mu\text{g}/\text{m}^3$		1983	1991	1993	2001	2007	2015	WHO
TSP	Year (day)	150 (300)	150 (300)	150 (300)	Delete			
PM <sub>10</sub>	Year (day)			80 (150)	70 (150)	50 (100)	50 (100)	<b>20</b>
PM <sub>2.5</sub>	Year (day)						25 (50)	<b>10</b> <b>(25)</b>

# Comparison of PM<sub>2.5</sub> standards between cities

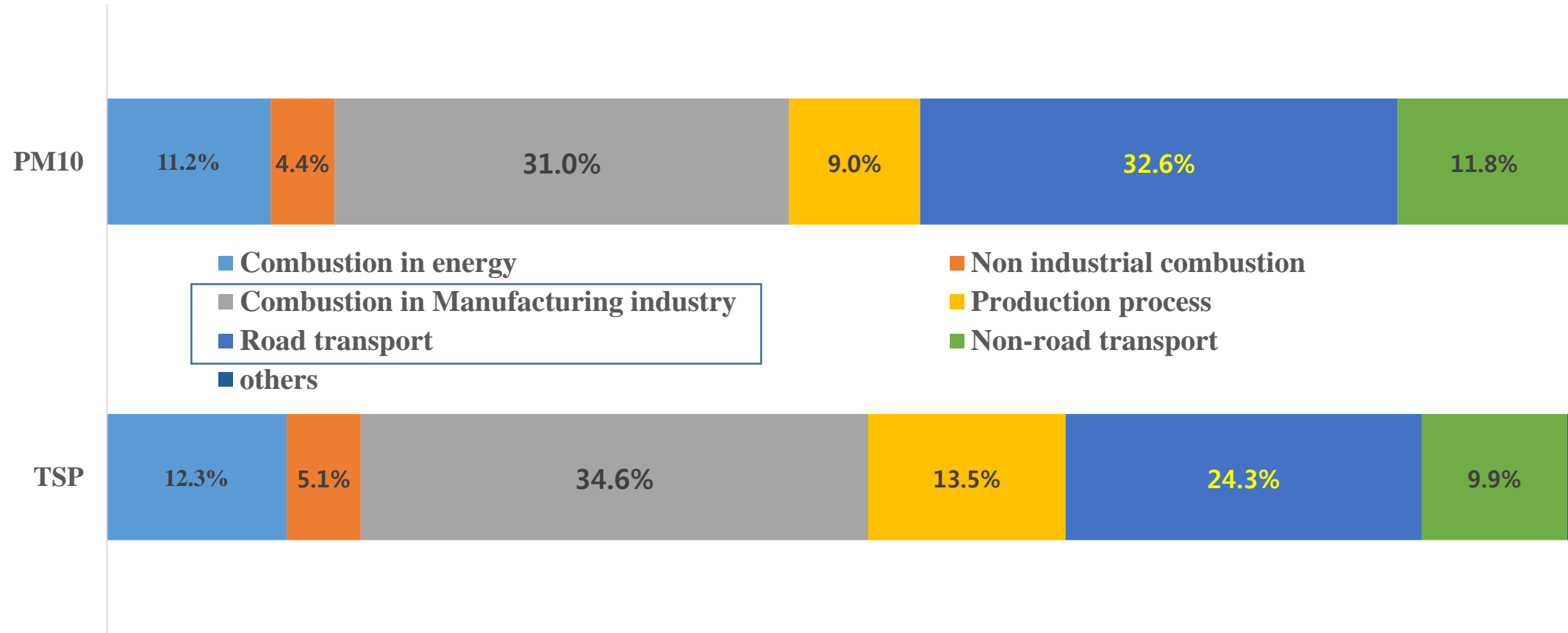
unit: $\mu\text{g}/\text{m}^3$	Korea	USA	Japan	EU	Australia	China
Daily average	50	35	35	-	25	75
Annual average	25	15	15	25	8	35
Year of introduction	2015	2006	2009	2010	2005	2012

# TSP & PM<sub>10</sub> emission trends from 1999 to 2013

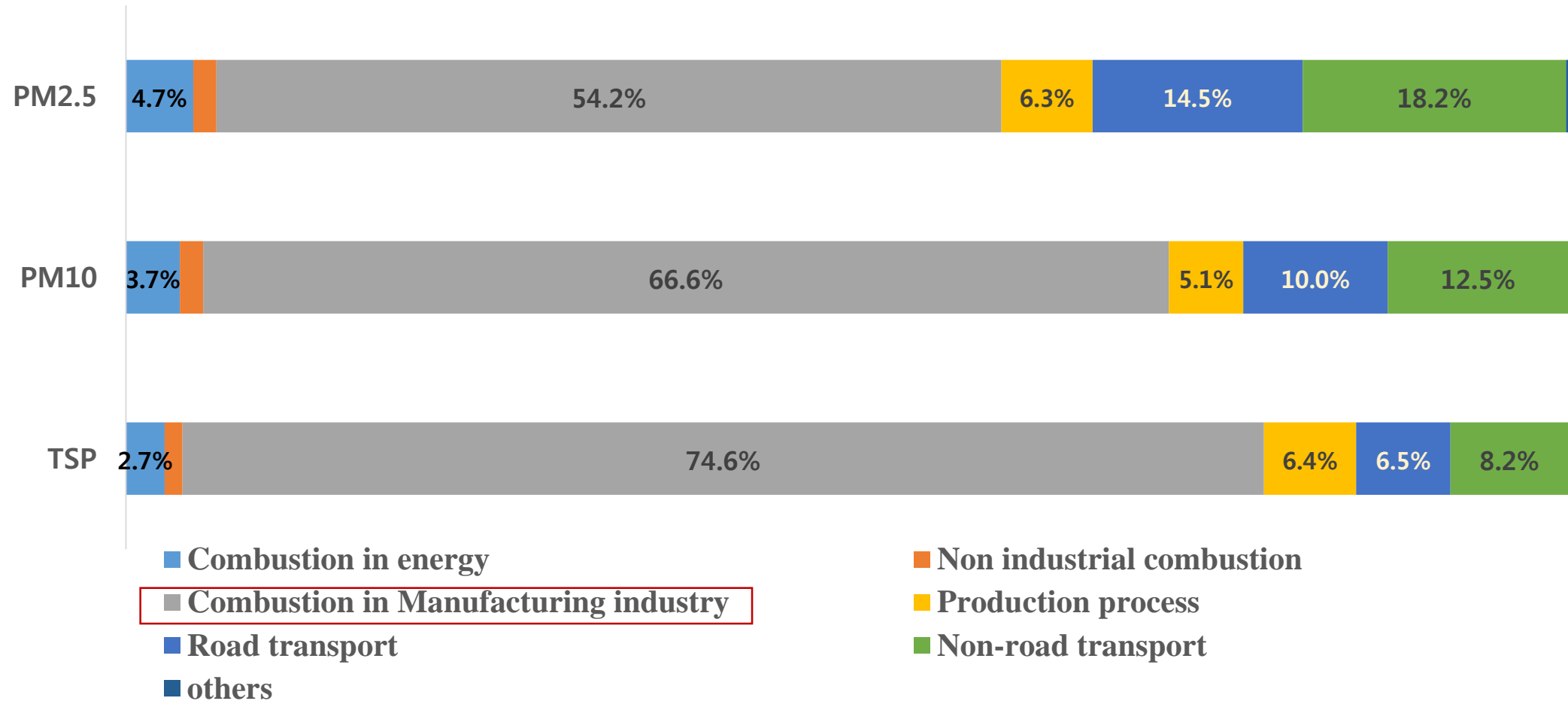


Source: National Air Pollutant Emission Service Database (<http://airemiss.nier.go.kr>)

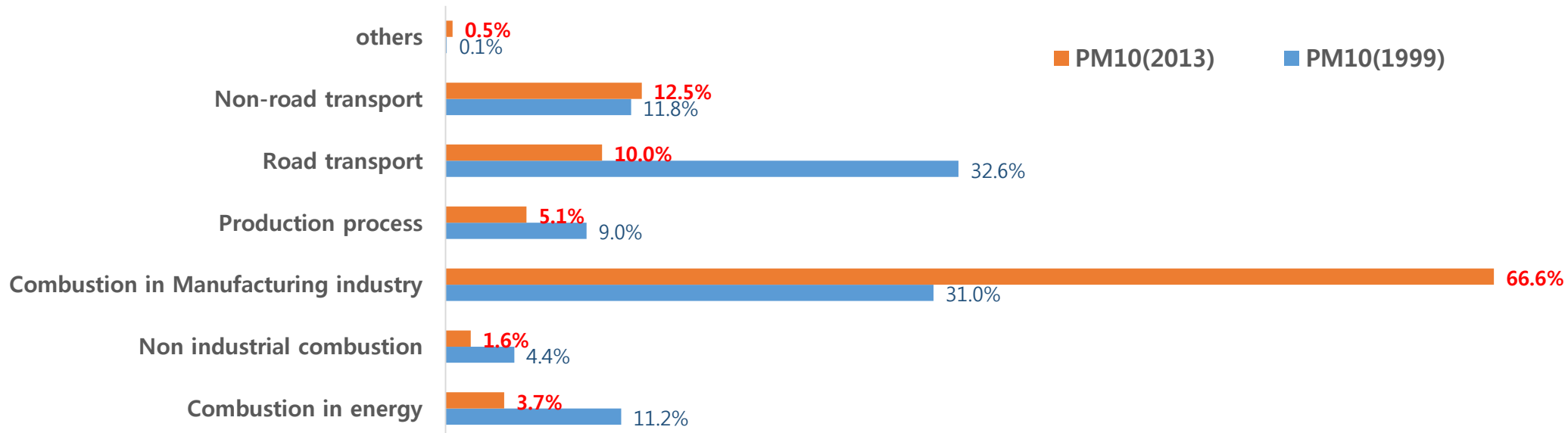
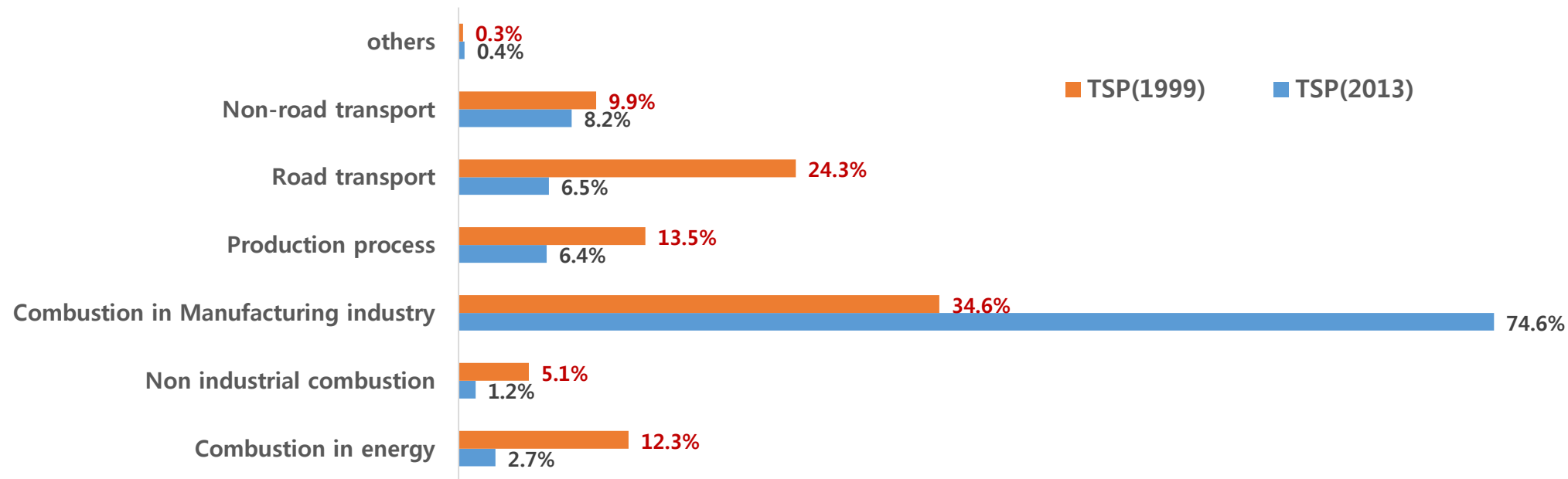
# TSP & PM<sub>10</sub> emission by source categories in 1999



# TSP & PM<sub>10</sub> emission by source categories in 2013

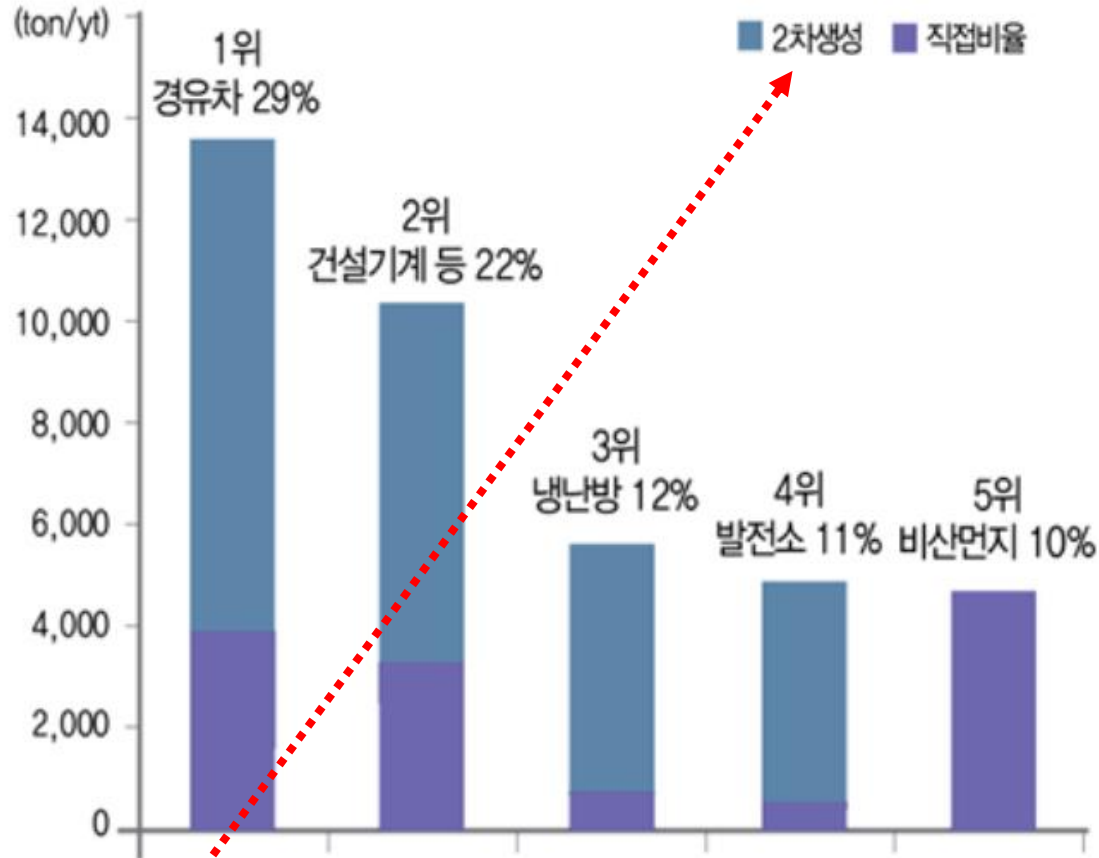




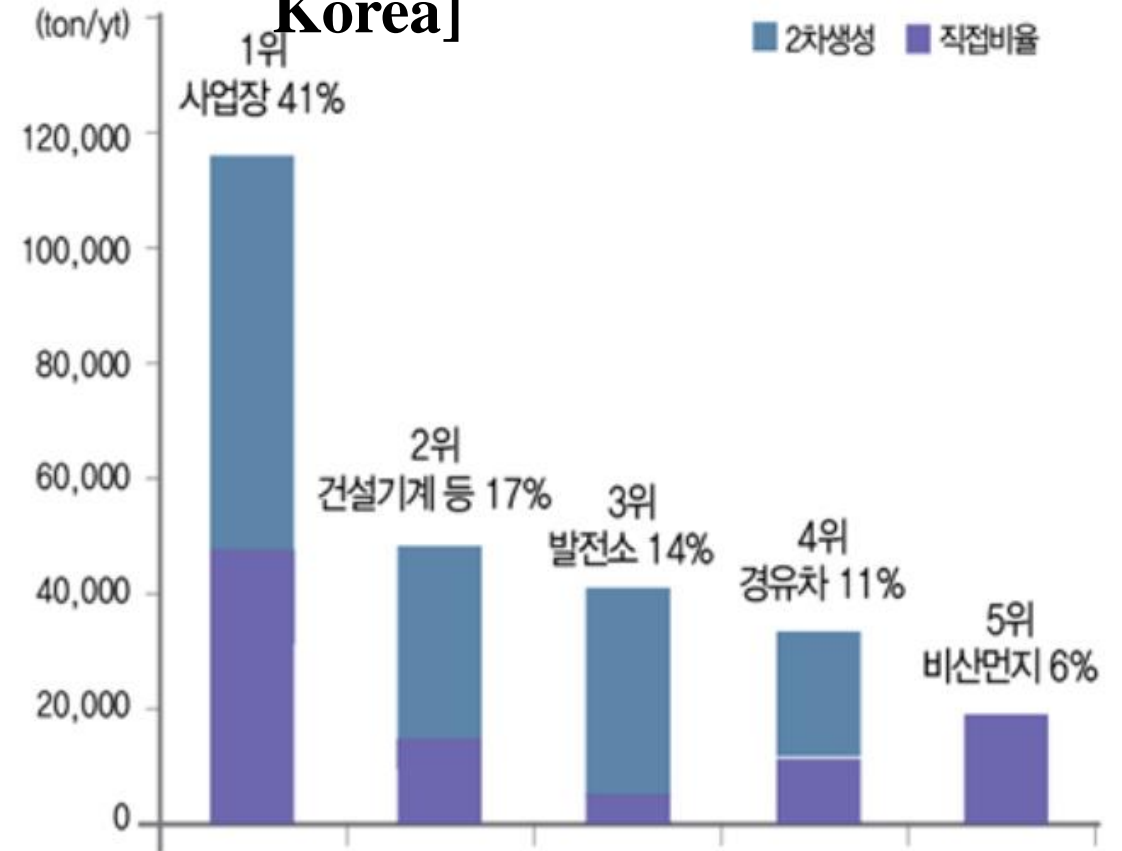


# Characteristics of PM<sub>2.5</sub> emissions (2013)

[Seoul metropolitan area]



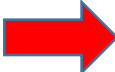
[Nation-wide of S. Korea]



- Indirect (secondary) PM<sub>2.5</sub> emissions

- The share of PM<sub>10</sub> emissions of power sector is 11% nationwide & 14% in the metropolitan area.
- Annual Air Pollutant Emissions by Industry (2015)

		TSP	SO <sub>x</sub>	NO <sub>x</sub>
Power Generation	Emissions (ton)	3,848	76,986	13,2678
	(%)	49.5	64.9	48.3
Primary Metal	Emissions (ton)	1,768	22,042	31,291
	(%)	22.8	18.6	11.4
Cement / Lime	Emissions (ton)	1,203	-	72,960
	(%)	15.5	-	26.6
Petroleum refining	Emissions (ton)	340	11,515	16,761
	(%)	4.4	9.7	6.1
Others	Emissions (ton)	619	8048	20,833
	(%)	8.0	6.8	7.6
TOTAL	Emissions (ton)	7,778	118,591	274,523


**Main sources of indirect (secondary) emissions of PM<sub>2.5</sub>**

*Note that it is based on the representative industry with TMS.*

Policy options to reduce PM<sub>2.5</sub> directly and/or indirectly :

**Power sector & Renewable energy**

# 1. Policy measures against Fine Dust in Coal Power Plants

- Shutdown aging coal-fired thermal power plants (10 plants)
- Retrofits
- Stronger emission standards for new coal power plants
  - 4 of planned & 5 of under construction coal power plants
- Adjustment of operation priority by source
  - **Economic Dispatch** → **Environmental Dispatch**

# 1-1. Shutdown 10 aging coal-fired thermal power plants



- plans to shut 10 ageing coal-fired power plants (3,345MW) by 2025
  - of the 10 to be shut, 2 will switch to **biomass** from coal in 2017
  - among the 43 coal power plants, 8 that are more than 20-years old will be **retrofitted**
  - while the rest, operational for under 20 years, will get expanded emission-reduction facilities
  - but, build **20 new coal-fired plants** by 2022 as planned (18,144MW)



# YeongHeung Coal-fired Power Plants



	unit	Plant #2			Plant #6		
		SO <sub>x</sub>	NO <sub>x</sub>	TSP	SO <sub>x</sub>	NO <sub>x</sub>	TSP
<b>Emissions [A]</b>	Ton	<b>1,475</b>	<b>1,062</b>	<b>111</b>	<b>521</b>	<b>564</b>	<b>39</b>
<b>Capacity</b>	MW	<b>800</b>			<b>870</b>		
<b>Year of installation</b>		<b>2004. 07</b>			<b>2014. 11</b>		
<b>Volume of electricity sales [B]</b>	GWh	<b>5,783</b>			<b>6,582</b>		
<b>Emissions per electricity sales volume [A]/[B]</b>	Ton/GWh	<b>0.46</b>			<b>0.17</b>		

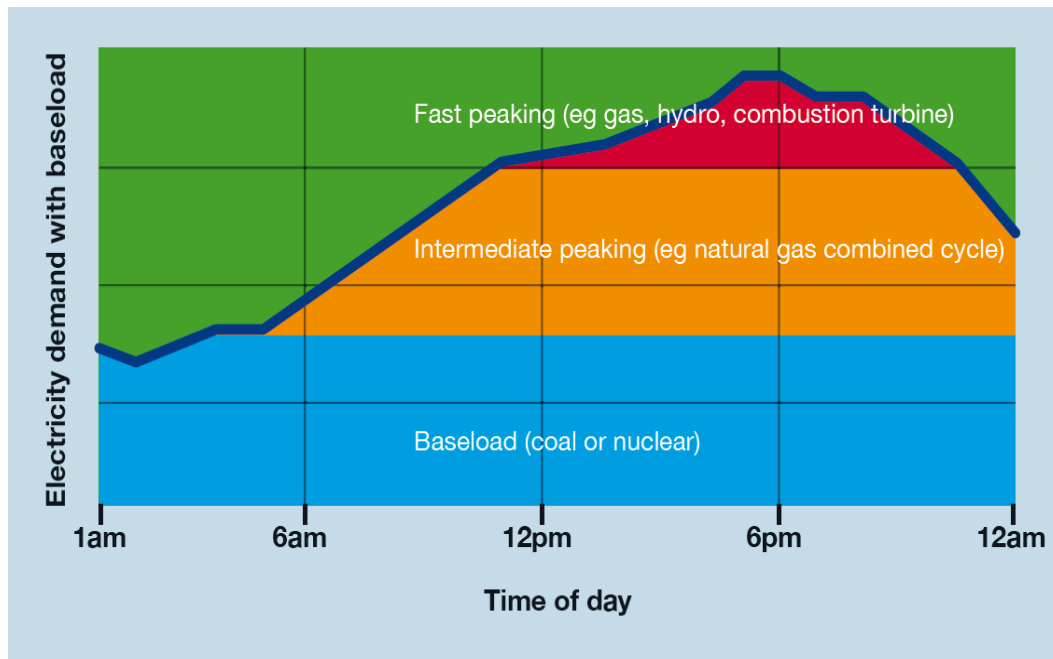
# Emissions of Air Pollutants by Power generation Fuel (2015)

	Unit	Coal	Gas	Oil	Total
Power generation [A]	GWh	201,070	106,503	9,394	316,967
		(63.4%)	(33.6%)	(3.0%)	(100%)
Air pollutant emissions [B]	Ton	183,027	25,208	12,073	220,308
		(83.1%)	(11.4%)	(5.5%)	(100%)
- TSP [C]	Ton	3,702	369	115	4,186
- SO <sub>x</sub>		71,618	327	5,054	76,999
- NO <sub>x</sub>		107,706	24,513	6,904	139,123
[B] / [A]	Ton/GWh	0.91	0.24	1.29	
[C] / [A]		0.0184	0.0035	0.0122	



# 1-2. Adjustment of operation priority

- Priority is given to a generator with low emission per generation rather than costs
  - Economic Dispatch (經濟急電) → **Environmental Dispatch** (環境急電)



# Example : Economic Dispatch → Environmental Dispatch

- Assumption
  - Period : 2016.02 - 2016.05
  - Total Power generation (100,780 GWh) is constant
  - Unit price (or cost) is constant
- Environmental dispatch scenario
  - Oil power plants → gas power plants
  - Changing coal-fired power generation and gas-fired power generation

# Example : Economic Dispatch → Environmental Dispatch

		Unit	Coal	Gas	Oil	Total
Unit price [A]		KRW/kWh	73.0	99.7	100.7	
Social cost of TSP [B]		1000 KRW/ton	68,949			
Unit emission of TSP per power generation		Ton/GWh	0.0184	0.0035	0.0122	
Power generation	BAU	GWh	63,377	32,033	5,370	100,780
	Scenario		32,033	68,747	0	100,780
	Difference [C]		- 31,344	+ 36,714	- 5,370	0
TSP emissions	BAU	Ton	1,166.1	112.1	65.5	1,343.8
	Scenario		589.4	240.6	0.0	830.0
	Difference [D]		-576.7	128.5	-65.5	-513.7
[A]x[C]		Million KRW	- 2,288,112	+ 3,660,386	- 540,759	+ 831,515
[B]x[D]			+ 39,763	- 8,860	+ 4,516	+ 35,419
TOTAL			- 2,288,112	+ 3,651,526	- 536,243	+ 866,934

		<b>Coal</b>	<b>Oil</b>	<b>Gas</b>	<b>Total</b>
<b>unit price/cost (KRW/kWh) [a]</b>		<b>73.0</b>	<b>100.7</b>	<b>99.7</b>	
<b>power generation (GWh) [b]</b>	<b>BAU</b>	<b>63,377.0</b>	<b>5,370.0</b>	<b>32,033.0</b>	<b>100,780.0</b>
	<b>Scenario</b>	<b>32,033.0</b>	<b>-</b>	<b>68,747.0</b>	<b>100,780.0</b>
	<b>difference</b>	<b>- 31,344.0</b>	<b>- 5,370.0</b>	<b>36,714.0</b>	<b>-</b>
<b>change of costs (million KRW)</b>	<b>[a]x[b]</b>	<b>- 2,288,112.0</b>	<b>- 540,759.0</b>	<b>3,660,385.8</b>	<b>831,514.8</b>

		<b>Coal</b>	<b>Oil</b>	<b>Gas</b>	<b>Total</b>
<b>Coefficient of emission (ton/GWh)</b>	<b>Sox</b>	<b>0.3562</b>	<b>0.538</b>	<b>0.0031</b>	
	<b>Nox</b>	<b>0.5357</b>	<b>0.7349</b>	<b>0.2302</b>	
	<b>TSP</b>	<b>0.0184</b>	<b>0.0122</b>	<b>0.0035</b>	
<b>Emissions (ton)</b>	<b>Sox</b>	<b>- 11,164.73</b>	<b>- 2,889.06</b>	<b>113.81</b>	<b>- 13,939.98</b>
	<b>Nox</b>	<b>- 16,790.98</b>	<b>- 3,946.41</b>	<b>8,451.56</b>	<b>- 12,285.83</b>
	<b>TSP</b>	<b>- 576.73</b>	<b>- 65.51</b>	<b>128.50</b>	<b>- 513.74</b>
<b>Social costs (million KRW/ton)</b>	<b>Sox</b>	<b>57.96</b>			<b>- 807,961.21</b>
	<b>Nox</b>	<b>4.85</b>			<b>- 59,586.28</b>
	<b>TSP</b>	<b>301.94</b>			<b>- 155,120.04</b>
<b>Total (million KRW)</b>					<b>- 1,022,667.53</b>
<b>Net benefits (million KRW)</b>					<b>- 191,152.73</b>

**Estimation of social costs due to the substitution of  
new coal-fired power plants**

- Estimate the **initial investment costs, annual operating & management costs,** and **environmental (external) costs** if 20 coal-fired power plants are built as scheduled
- Comparing and analyzing the difference in costs when **replacing** some or all of the new coal-fired power plants with LNG combined power generation, solar power generation or wind power generation.

# **COSTS**

- **Initial investment costs (construction costs)**
- **Annual O&M costs including fuel costs**
- **Environmental (external) costs**
  - **Air pollutants : NO<sub>x</sub>, SO<sub>x</sub>, PM<sub>10</sub>, CO<sub>2</sub>**



# Estimation results

- The estimated total costs will be **265 trillion KWR** if new 20 coal-fired power plants are built on schedule and operate at a 90.7% operation rate by 2035.

(Unit: 100 billion KWR)

<b>Initial Investment</b>	<b>Variable Costs</b>	<b>Environmental Costs</b>	<b>Total Costs</b>
<b>180.4</b>	<b>1,271.6</b>	<b>1,200.5</b>	<b>2,652.5</b>
<b>7%</b>	<b>48%</b>	<b>45%</b>	<b>100%</b>

# Scenario Analysis

- Comparing the difference in costs when **replacing** some or all of the new coal-fired power plants with LNG combined power generation, solar power generation or wind power generation.
- **8 scenarios**

Year	Coal-fired plant		Scenario							
	Name	Capacity	I	II	III	IV	V	VI	VII	VIII
2015	Dangjin#9	1020	LNG-fired power plants	LNG-fired power plants	LNG-fired power plants	LNG-fired power plants	LNG-fired power plants	Coal-fired power plant	Coal-fired power plant	Coal-fired power plant
2016	Dangjin#10	1020								
	Samcheck Green#1	1022								
	Samcheck Green#2	1022								
	Bukpyeong#1	595								
	Bukpyeong#2	595								
	Taeon#9	1050								
	Taeon#10	1050								
	Shin	1000								
Boryeong#1	350									
2017	Shin	1000								
	Boryeong#2									
2019	Shin Seocheon#1	1000	PV	Wind-Land	Wind-ocean	PV	PV	Wind-Land	PV	
	Gangneung A.#1	1040								
2020	Gangneung A.#2	1040								
	Goseong Hai#1	1040								
2021	Goseong Hai#2	1040								
	Samcheck Th.#1	1050								
	Samcheck Th.#2	1050								
	Dangjin Echo#1	580								
2022	Dangjin Echo#2	580								

# Results by Scenarios

(Unit: million KWR)

<b>Scenario</b>	<b>Initial investment</b>	<b>Variable costs</b>	<b>Environmental costs</b>	<b>Total costs</b>
<b>BAU</b>	<b>180,427.4</b>	<b>1,271,571.2</b>	<b>1,200,463.1</b>	<b>2,652,461.7</b>
<b>I</b>	<b>104,459.7</b>	<b>3,245,827.3</b>	<b>123,206.7</b>	<b>3,473,493.8</b>
<b>II</b>	<b>321,027.9</b>	<b>1,936,180.7</b>	<b>73,422.7</b>	<b>2,330,631.3</b>
<b>III</b>	<b>290,042.3</b>	<b>2,066,169.5</b>	<b>73,422.7</b>	<b>2,429,634.6</b>
<b>IV</b>	<b>551,062.3</b>	<b>2,118,921.5</b>	<b>73,422.7</b>	<b>2,743,406.6</b>
<b>V</b>	<b>305,203.9</b>	<b>1,999,184.1</b>	<b>73,422.7</b>	<b>2,377,810.7</b>
<b>VI</b>	<b>362,938.4</b>	<b>759,660.0</b>	<b>715,393.3</b>	<b>1,837,991.7</b>
<b>VII</b>	<b>331,952.8</b>	<b>889,648.9</b>	<b>715,393.3</b>	<b>1,936,994.9</b>
<b>VIII</b>	<b>347,114.4</b>	<b>822,663.4</b>	<b>715,393.3</b>	<b>1,885,171.1</b>

## **2. Role of Renewable Energy**

# Energy Consumptions by Sectors (unit: MTOE)

Sector	2000		2010	2015		Annual growth rate (%)
Industry	83.9	<b>56.0</b>	116.9	136.7	<b>62.5</b>	3.3
Transportation	30.9	<b>20.6</b>	36.9	40.3	<b>18.4</b>	1.8
Households & commercial	32.4	<b>21.6</b>	37.3	36.4	<b>16.7</b>	0.8
Other	2.6	<b>1.7</b>	4.5	5.2	<b>2.4</b>	4.7
Total	149.9	<b>100</b>	195.6	218.6	<b>100</b>	2.5

# Prospect of total primary energy & final energy (BAU)

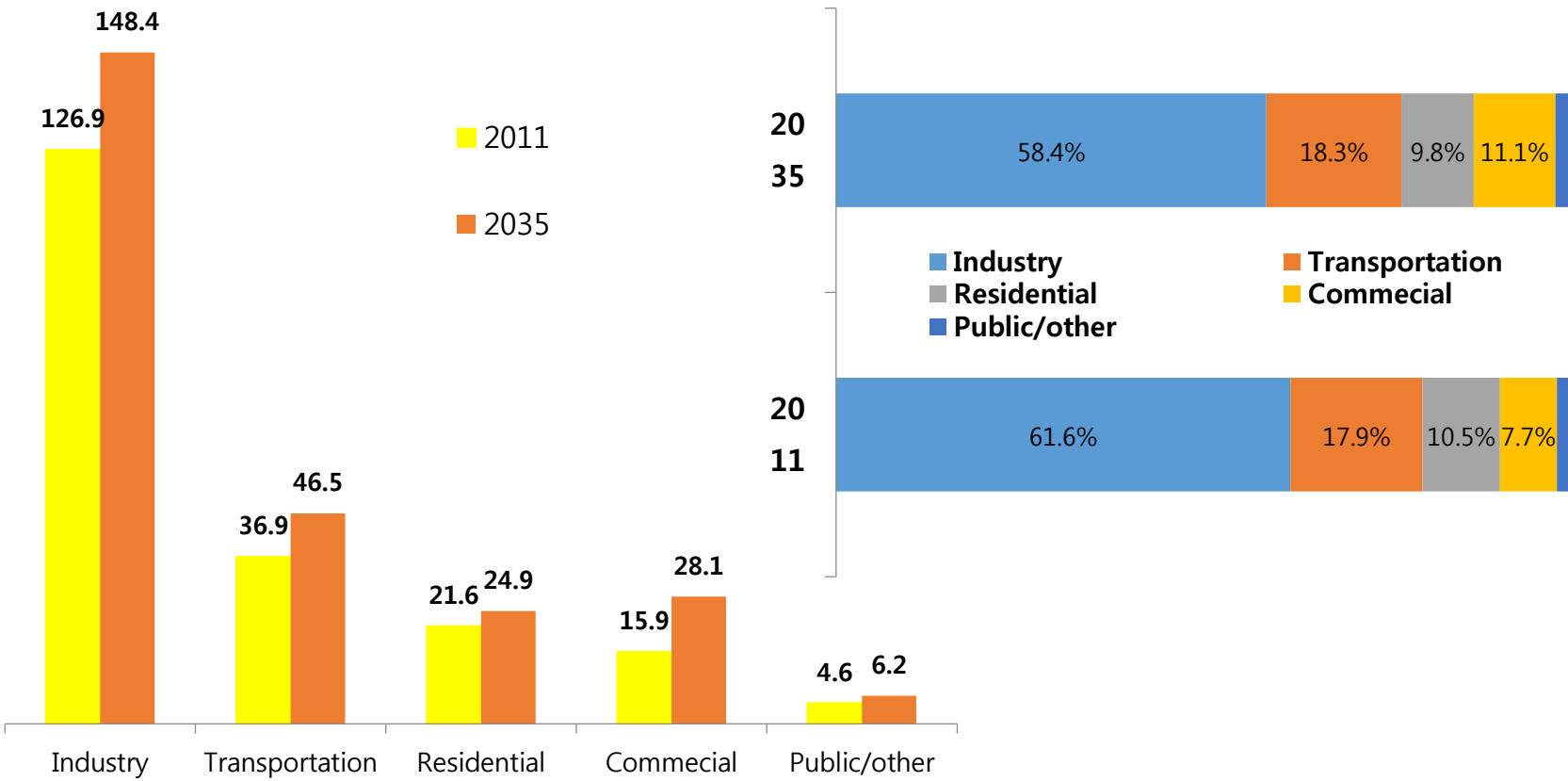
2<sup>nd</sup> Master Plan for National Energy

unit: MTOE

Primary energy	2011	2035	Annual growth rate	Final energy	2011	2035	Annual growth rate
Coal	86.6 (30.3)	112.4 (29.7)	1.24%	Coal	33.5 (16.3)	38.6 (15.2)	0.58%
Petroleum	105.1 (38.1)	101.5 (26.9)	-0.15%	Petroleum	102.0 (49.5)	99.3 (39.1)	-0.11%
LNG	46.3 (16.8)	73.3 (19.4)	1.93%	City gas	23.7 (11.5)	35.3 (13.9)	1.68%
Hydro	1.7 (0.6)	2.0 (0.5)	0.70%	Electricity	39.1 (19.0)	70.2 (27.6)	2.47%
Nuclear	32.3 (11.7)	<b>70.0</b> <b>(18.5)</b>	3.28%	Heat	1.7 (0.8)	3.3 (1.3)	2.82%
Renewables /other	6.6 (2.4)	<b>18.8</b> <b>(5.0)</b>	4.44%	Renewables	5.8 (2.8)	7.4 (2.9)	1.01%
<b>Total</b>	<b>275.7</b> <b>(100)</b>	<b>377.9</b> <b>(100)</b>	<b>1.32%</b>	<b>Total</b>	<b>205.9</b> <b>(100)</b>	<b>254.1</b> <b>(100)</b>	<b>0.88%</b>

# Prospect of Energy Demand by Sectors in 2035

unit: MTOE



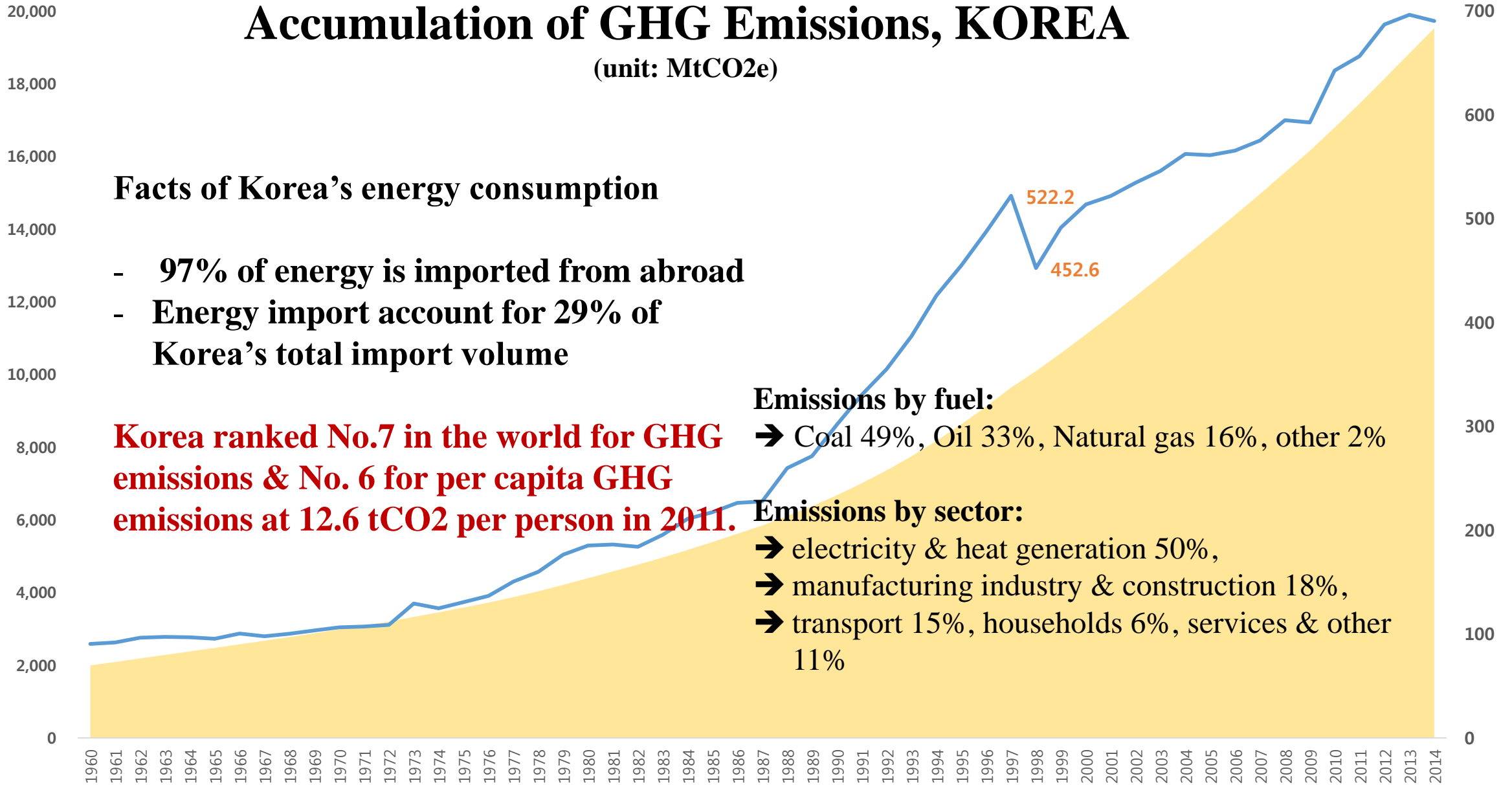


# Implications

- **Fine dust (TSP, PM<sub>10</sub>, PM<sub>2.5</sub>), and SO<sub>x</sub>, NO<sub>x</sub>, Carbon dioxide emissions will continue to grow.**

# Accumulation of GHG Emissions, KOREA

(unit: MtCO<sub>2</sub>e)



## Facts of Korea's energy consumption

- 97% of energy is imported from abroad
- Energy import account for 29% of Korea's total import volume

**Korea ranked No.7 in the world for GHG emissions & No. 6 for per capita GHG emissions at 12.6 tCO<sub>2</sub> per person in 2011.**

### Emissions by fuel:

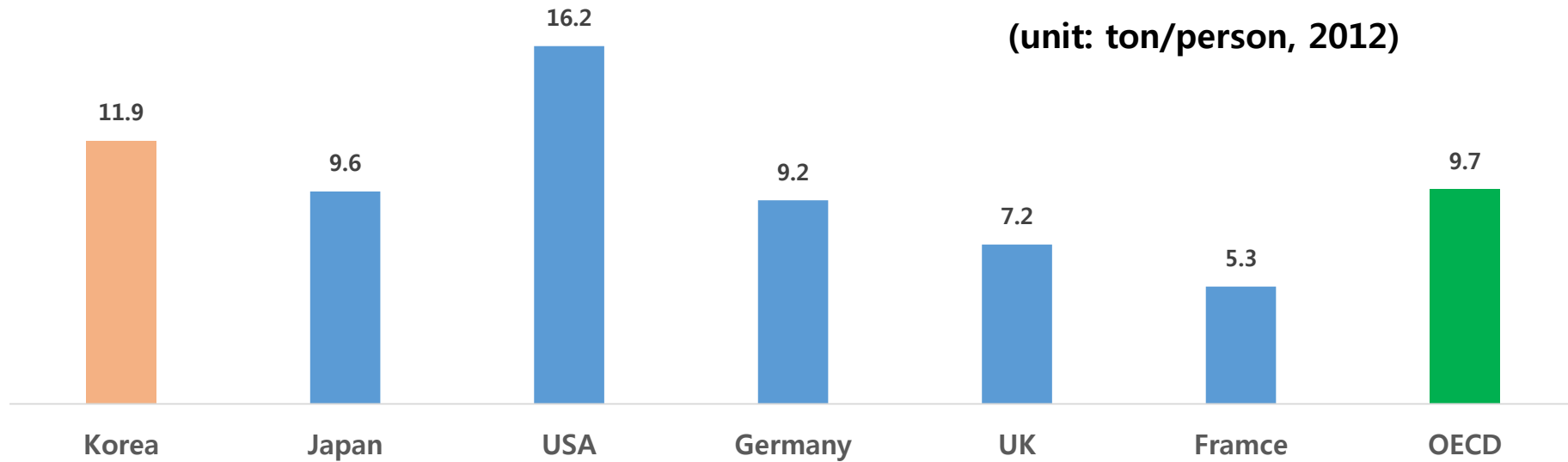
→ Coal 49%, Oil 33%, Natural gas 16%, other 2%

### Emissions by sector:

- electricity & heat generation 50%,
- manufacturing industry & construction 18%,
- transport 15%, households 6%, services & other 11%

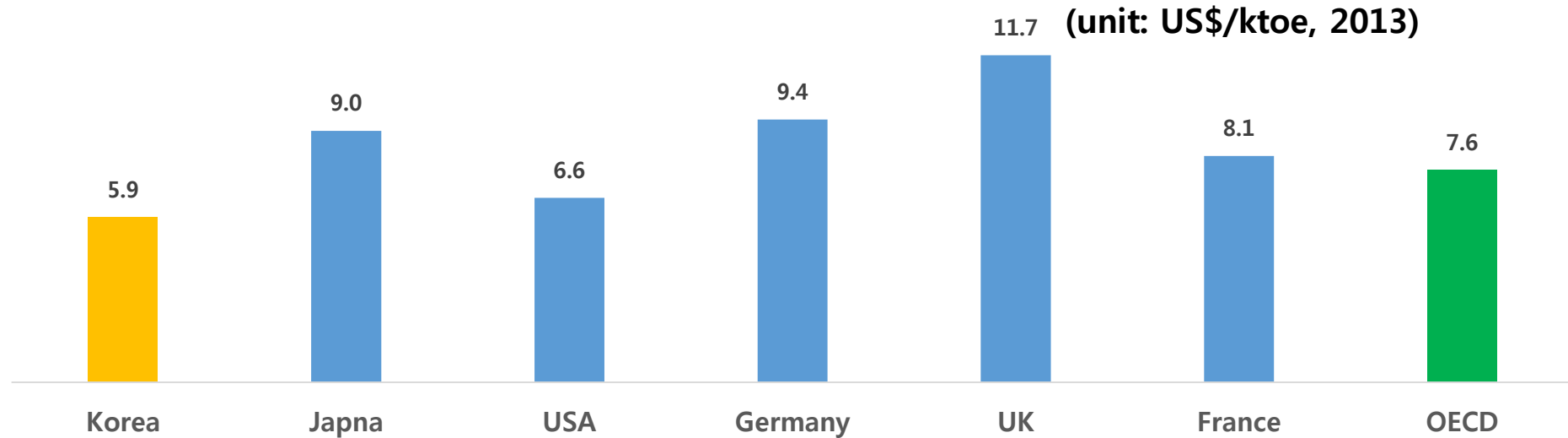
# CO2 emission per capita

(unit: ton/person, 2012)

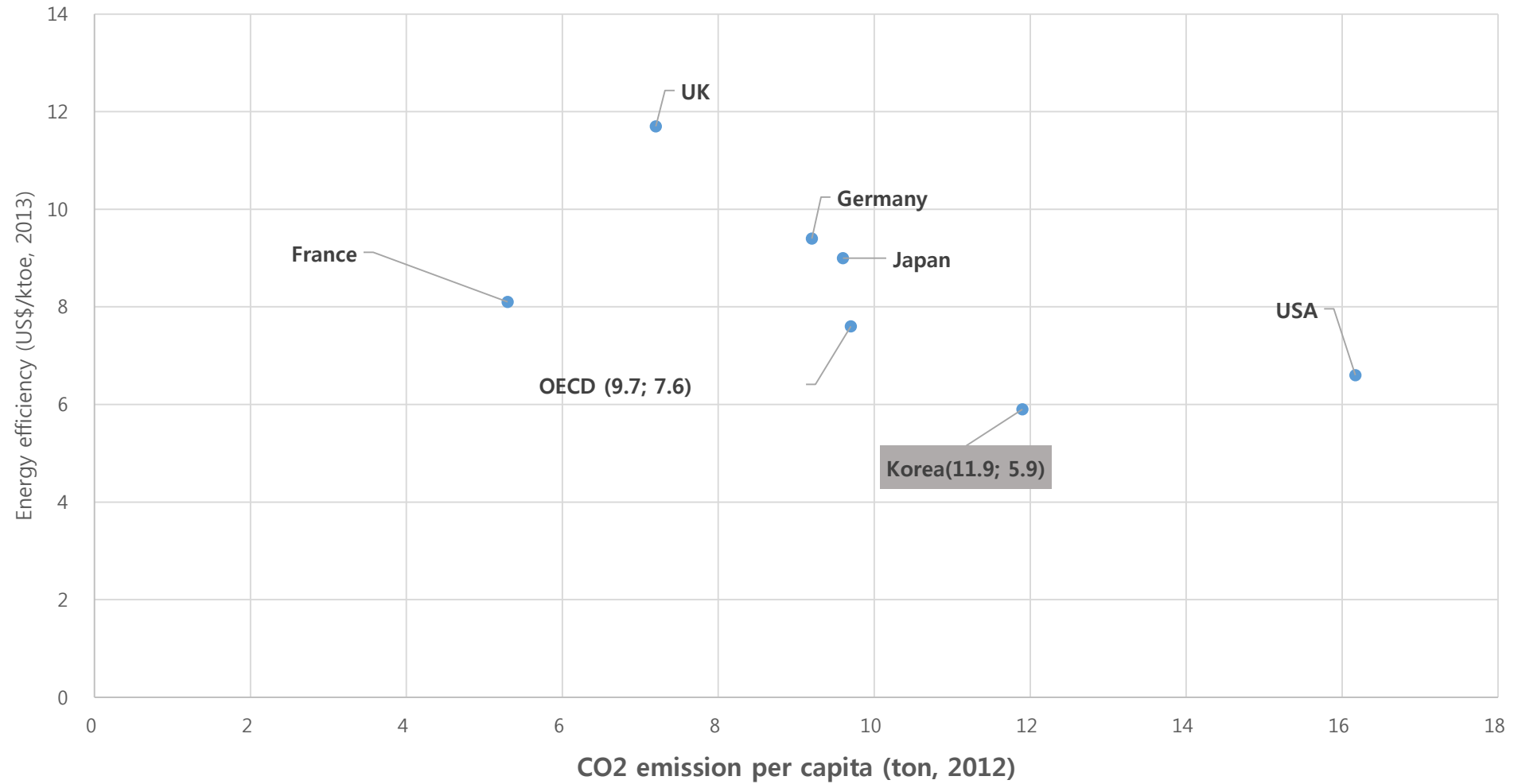


# Energy Efficiency

(unit: US\$/ktoe, 2013)

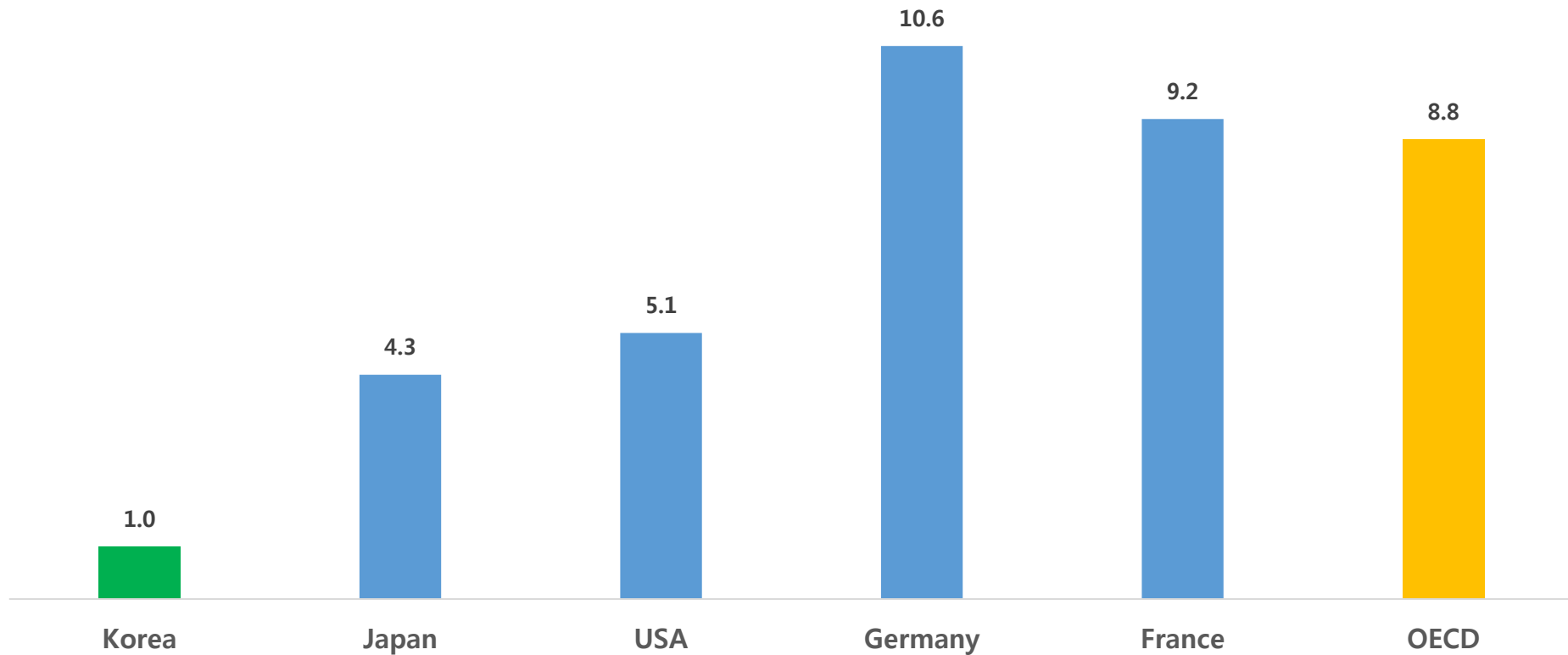


# CO2 emission per capita vs Energy efficiency

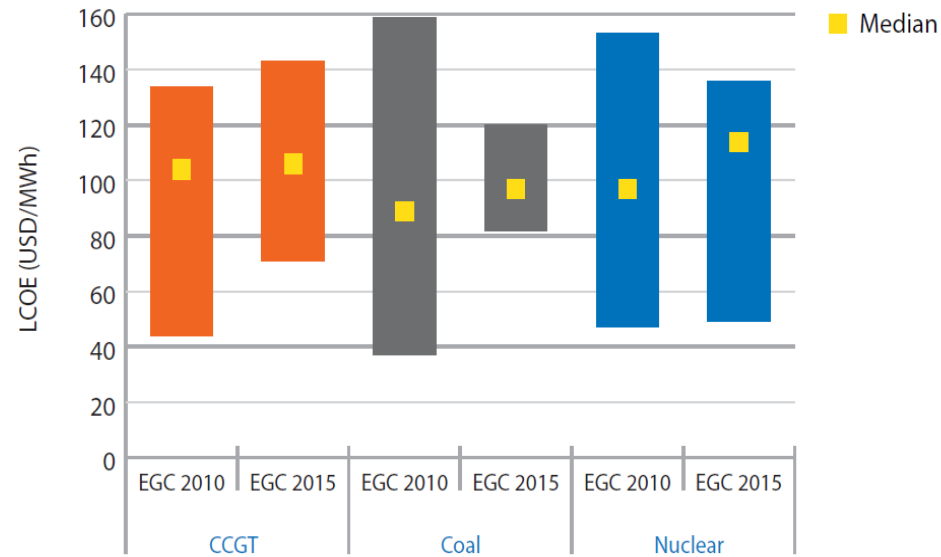


# Renewable energy proportion in primary energy

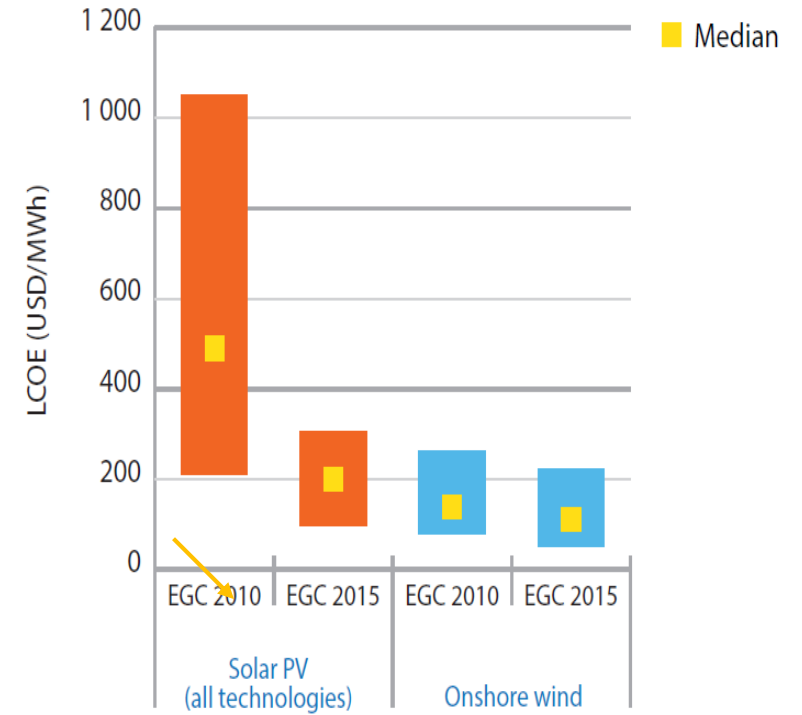
(unit: %, 2013)



**Figure ES.3: EGC 2010 and EGC 2015 LCOE ranges for baseload technologies**  
(at 10% discount rate)



\* EGC 2010 results have been converted to USD 2013 values for comparison.



Source: IEA/NEA, Projected costs of generating electricity, 2015 (p.18)

# New Renewable Energy Plan 3020

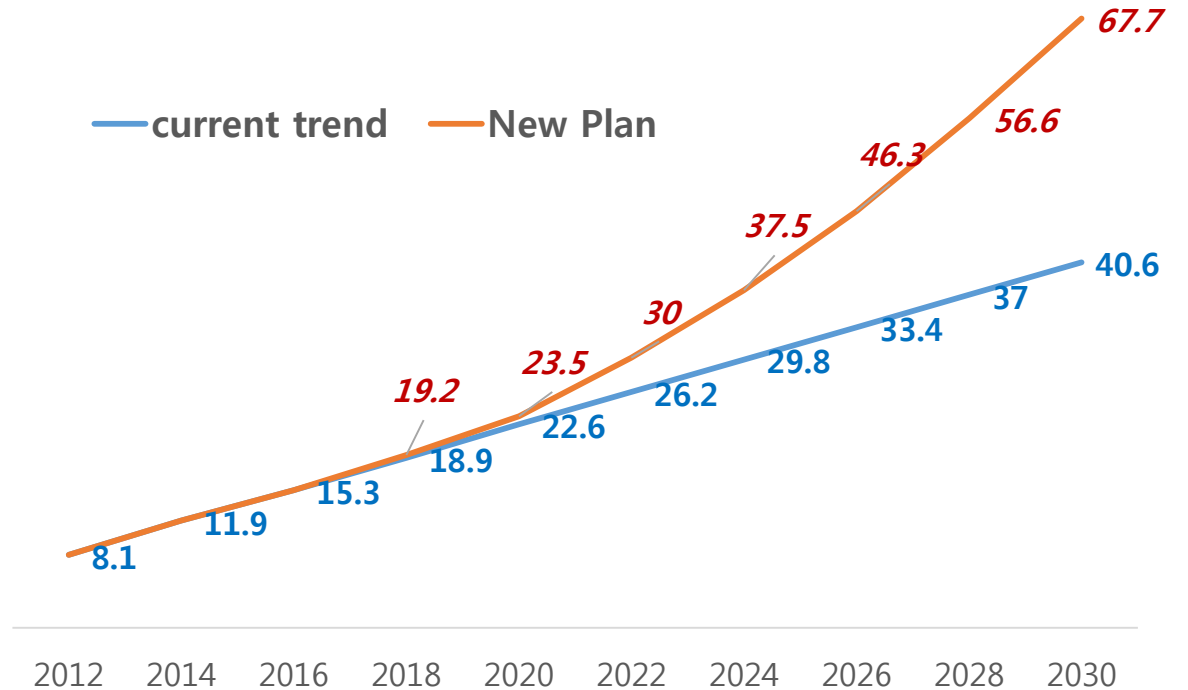
- 11% of Renewable energy in primary energy
  - Change of target year : 2035 → 2025
- 20% of renewable energy in 2030
  - Based on electricity capacity
  - Portion of PV & wind power increased 72% (2016.11)

Energy Mix	Nuclear	Coal	Renewable	LNG
2018	32%	38%	8%	20%
2022	28%	32%	11%	28%
2030	18%	27%	20%	33%

### Mix of Renewable Energy Source (MW)

	2016	2018	2022	2030
PV	4.5 (29.4%)	7.5 (39.0%)	15.3 (51.0%)	37.0 (54.6%)
Wind	1.0 (6.5%)	1.4 (7.3%)	3.9 (13.0%)	18.3 (27.0%)
Other	9.8 (64.1%)	10.3 (53.7%)	10.8 (36.0%)	12.4 (18.4%)
Total	15.3 (100)	19.2 (100)	30.0 (100)	67.7 (100)

### Forecasting of Renewable Energy Capacity (unit: GW)





## **Strategies**

- Prosumer
- Green Pricing
- Renewable SPC
- RPS

## **Barriers**

- Social acceptability
- NIMBY

**Thank you**  
yscho@korea.ac.kr