SO_2, NO_2 Emission Inventory in Korea

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1. Background

- The acidity of rainfalls was very severe in Korea.
  - **"The Characteristics and Damage of Acid Rain in Korea" by National Environmental Research Institute of Korea(1995)**
- Acid rain of pH 3.5 was fallen at Sangmoon-Dong, Seoul.
  - **February, 1994**
- Anthropogenic SO_2 emission in Far East Asian Region is about 24,000,000 tons, almost same level of North America or Europe.
- SO_2 & NO_2 : Causes of acid rain
  → Necessity of the emission inventory
- The inventory includes economic costs of mitigating SO_2 & NO_2 emission+ the cost of damage induced by from acid rain.

2. Objectives of Study

Situation There...

- The inventory of SO_2 and No_2 emissions are calculated by detailed regional level in Korea.
- In Korea, Ministry of Environment publishes the SO_2 and NO_2 emission data by provinces.
- The inventory data of SO_2 and NO_2 emission are not available at the local governmental level.
- It is more limited to project future SO_2 and NO_2 emission, based on the data of province level.

2. Objectives of Study (Cont'd)

What Includes...

1. The GIS is to develop to represent the SO_2 and, No_2 emission by local governmental level & provinces.
2. The data of provinces are collected and modified to show them at the map through GIS.
3. This work is extended to the local governmental level.

- It is necessary to figure out SO_2 and NO_2 emission in order to develop policy programs to mitigate them.
- The economic costs of mitigating SO_2 and NO_2 emissions will be analyzed, including the cost of damage induced by from acid rain.

3. Calculation of SO_2 and NO_2 Emission by Detailed Region

- Emissions of pollutants in Korea that cause the acid rain are calculated by local government, based on the data of 1996.
- Fuel types:
  gasoline, kerosene, diesel(sulfur content 1.0, 0.1%), B-A, B-B, B-C(sulfur content 4.0, 1.6, 1.0, 0.3%), anthracite, bituminous, LNG and LPG
- Emission sectors :
  power generation, industry, heating & transportation
  Cement and steel industries using bituminous in the process of production are separately treated.
- Basic data source:
  Heating, industry & transportation:Ministry of Environment,1996
  Power generation, the actual fuel type and consumption: Korea Electric Power Corporation (KEPCO),1996

4. Emission Calculation by Detailed Regional Classifications

The total process is made up with 3 steps.

- Available Data for Each Detailed Regional Classifications
- Calculated fuel consumption in Heating, Industry, Transportation and Power Generation
- Based on the calculation, brought up with SO_2 and NO_2 Emission by 232 local governments.

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

1) Available Data for Each Detailed Regional Classifications

- According to the 'Clean Air Act' of Korea, the fuel types that are allowed in each local government are different: the mandatory region for diesel or lower sulfur B-C and the mandatory region for LNG.

<Table 1> Supplied Extension State of Low-Sulfur Residual Oil

Type	1981	1982	1988	1992	1993	1994	1995	1996	1997
B -C Oil	Seoul (1.6%)	8 city/ District (1.6%)	27 city/ District (1.6%)	34 city/ District (1.6%)	18 city/ District (1.6%) 20 city/ District (1.0%)	17 city/ District (1.6%) 21 city/ District (1.0%)	19 city/ District (1.6%) 22 city/ District (1.0%)	42 city/ District (1.0%)	37 city/ District (1.0%) 24 city/ District (0.5%)
Diesel	Seoul (0.4%)	8 city/ District (0.4%)	27 city/ District (0.4%)	34 city/ District (0.4%)	38 city/ District (0.2%)	38 city/ District (0.2%)	41 city/ District (0.2%)	63 city/ District (0.1%)	Whole Nation (0.1%)

Numbers in parenthesis are sulfur content.

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

- In1996, Ministry of Environment made even stronger amendment for mandatory supply of lower sulfur fuels, expanding using areas.
  (B-C Oil: 1.0%⌫ 0.5% until 1997 and 0.5%⌫ 0.3% from 2001, Diesel: 0.2%⌫ 0.1%)
- It is mandatory to use 'clean fuel' such as LNG in the areas where the environmental standard would be violated. From 1988, it has been mandatory to use 'clean fuel' in commercial and public buildings in Seoul, whose capacity of boiler was bigger than 2.0 ton.
- Regulation reinforced (1991) :
  - **Commercial & public buildings in Seoul with boiler capacity bigger than 0.5 ton**
  - **Residential apartments in Seoul with floor spaces larger than 30 'pyung'**
  - **Commercial & public buildings in Seoul metropolitan areas (14 cities) with boiler capacity bigger than 2.0 ton**
  - **Residential central heating apartments in Seoul metropolitan areas (14 cities) with floor spaces larger than 35 'pyung'.**
- Reinforcement extended to other major cities like Pusan & Taegu.

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

2) Heating

- Fuel consumption for heating by detailed regions is calculated by the share of the number of households and fuel types of each residential type in province. Process of calculation :

Fuel Consumption (Local) = Fuel Consumption (Province) ×
∑(Share of Residential Type(Local/Province) ×Share of Fuel Types) (1)

- Number of households are calculated by residential types.
  (individual house, apartment, tenement house, complex house & house in store)
- To check whether certain fuel types are allowed in specific region or not to disaggregate to local government level.
- Fuel consumption patterns are different, depending on whether the area is urban or not. Therefore, it is necessary to classify the area, and then calculate fuel consumption by types.

<Table 2> Share of Fuel Consumption by Residential Type

	House		Apartment		Tenement		Complex		Store	
	U*	R*	U	R	U	R	U	R	U	R
Anthracite Coal	0.94	0.98	0.02		0.01		0.01		0.02	0.02
kerosene	0.76	0.91	0.08	0.01	0.07	0.03	0.02	0.00	0.07	0.05
Diesel	0.76	0.94	0.08	0.01	0.09	0.02	0.01	0.00	0.06	0.03
B-C			1.00	1.00						
LPG	0.74	0.90	0.11	0.02	0.08	0.02	0.01	0.01	0.06	0.05
LNG	0.38		0.44		0.12		0.03		0.03	

*** U - Urban Area, R- Rural Area**

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

3) Industry

- In Korea, the emission from manufacturing industries is monitored by amounts of annual fuel consumption. Hence, we calculate amounts of emission from industrial sector by detailed regions as follows: the number of emitters is multiplied by the weighted emission index.

Fuel Consumption = (Fuel Consumption of Province ×Emission Index of Detailed Region)/ (Emission Index of Province) (2)

Emission Index = Number of Manufacturer by Scale Types ×Weight (3)

- Also possible to calculate the amounts of emission from agriculture, mining and manufacturing industries. Since these proxy variables have little relationship with fuel consumption, Likely the approximation will have larger gaps. Hence, the latter method is not considered.

<Table 3> Fuel Consumption and Weight by Scale Type

	Fuel Consumption	Weight
1	10,000 -	150
2	2,000 -10,000	60
3	1,000 - 2,000	15
4	200 - 1,000	6
5	- 200	1

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

4) Transportation

- Fuel consumption is different, depending on transportation modes.
- To allocate amounts of fuel consumption to each detailed region by fuel types. **(Equations (4) –(6)).**
- To calculate numbers of vehicles based on registration numbers of vehicles by vehicle types in each detailed region.

Gasoline = Gasoline Consumption in Province
X (No. of Passenger Cars in Detailed Region X Road Index)
/ (No. of Passenger Cars in Province X Road Index) (4)

Diesel = Diesel Consumption in Province
X (No of (Bus + Truck + Special Vehicle) in Detailed Region X Road Index)
/ (No of (Bus + Truck + Special Vehicle) in Province X Road Index) (5)

B-A, B-B, B-C Oil = B-A, B-B, B-C Oil Consumption in Province
X (Tones of Ship-in-and-out in Detailed Region)
/ (Tones of Ship-in-and-out in Province (6)

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

- The road index is defined as length of road paved in detailed region multiplies number of lanes, as in equation (7).
- Road classification:
  high-way, national road, province road & detailed regional road

Road Index = Length of High-way ⨯4
+ Length of (National + Province + Detailed Regional) Road⨯2 (7)

- If the number of vehicle registration at the detailed regional level is not available in province level, the number of population in that province is used for the proxy variable.

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

5) Power Generation

- The actual fuel consumption data of 1995 in each power plant located in specific detailed region is used for the calculation of emission in this sector. (KEPCO, 1996)

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

6) SO_2 and NO_2 Emission

- SO_2 and NO_2 emission in heating, industry and transportation sectors in each detailed region is calculated, depending on types of fuel.
- These calculations are represented in Equations (8) – (10), basically different emission factors multiplied by fuel consumption.

Coal: Emission(Ton/Year) = Emission Factor(kg/Ton)
Fuel Consumption(Ton/Year)
10^{-3}(Ton/kg) **(8)**

Oil: Emission(Ton/Year) = Emission Factor(kg/kl)
Fuel Consumption(kl/Year) 10^{-3}(Ton/kg) **(9)**

Gas: Emission(Ton/Year) = Emission Factor(kg/10^3m^3, kg/kl)
Fuel Consumption(10^3m^3/Year, kl/Year) 10^{-3}(Ton/kg) **(10)**

4. Emission Calculation by Detailed Regional Classifications (Cont'd)

•Especially in transportation sector, No_2 emissions from gasoline and diesel are calculated as shown in equation (11).

Emission(Ton/Year) = Vehicle Index

- **Driving Distance per day by Vehicle Types(km/day)**
- **Emission Factor(g/km)**
- **365(days/year)**
- **10^{-6}(Ton/year)** **(11)**

In <Table 4>, driving distance per day by vehicle type and emission factors are presented, which are based on the study of National Environmental Research Institute of Korea.

<Table 4> Driving Distance per Day by Vehicle Type and Emission Factor

Type		Driving Distance per Day	Emission Factor
Passenger Car		48.7	0.41
Taxi		257.8	0.79
Bus	Small	71.9	1.45
	Medium	62.3	1.65
	Large	242.0	13.29
Truck	Small	73.0	1.49
	Medium	99.0	1.65
	Large	166.2	13.65

5. Emission Inventory Map in Province Level

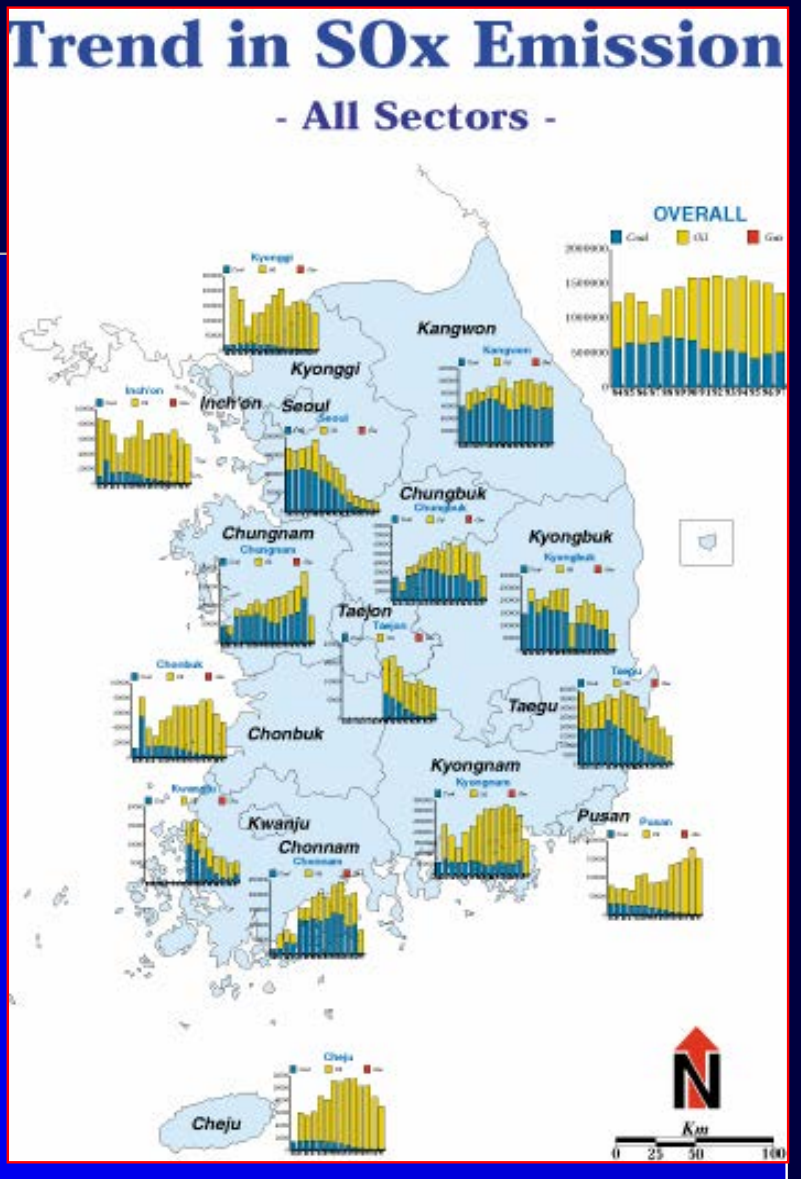
1) So_2 Emission

- So_2 emission in each province is shown at <Figure 1>-<Figure 4>.

  - <Figure 1> : So_2 emission from all sector
  - <Figure 2> : So_2 emitted from coal
  - <Figure 3> : So_2 emitted from oil
  - <Figure 4> : So_2 emission from LNG

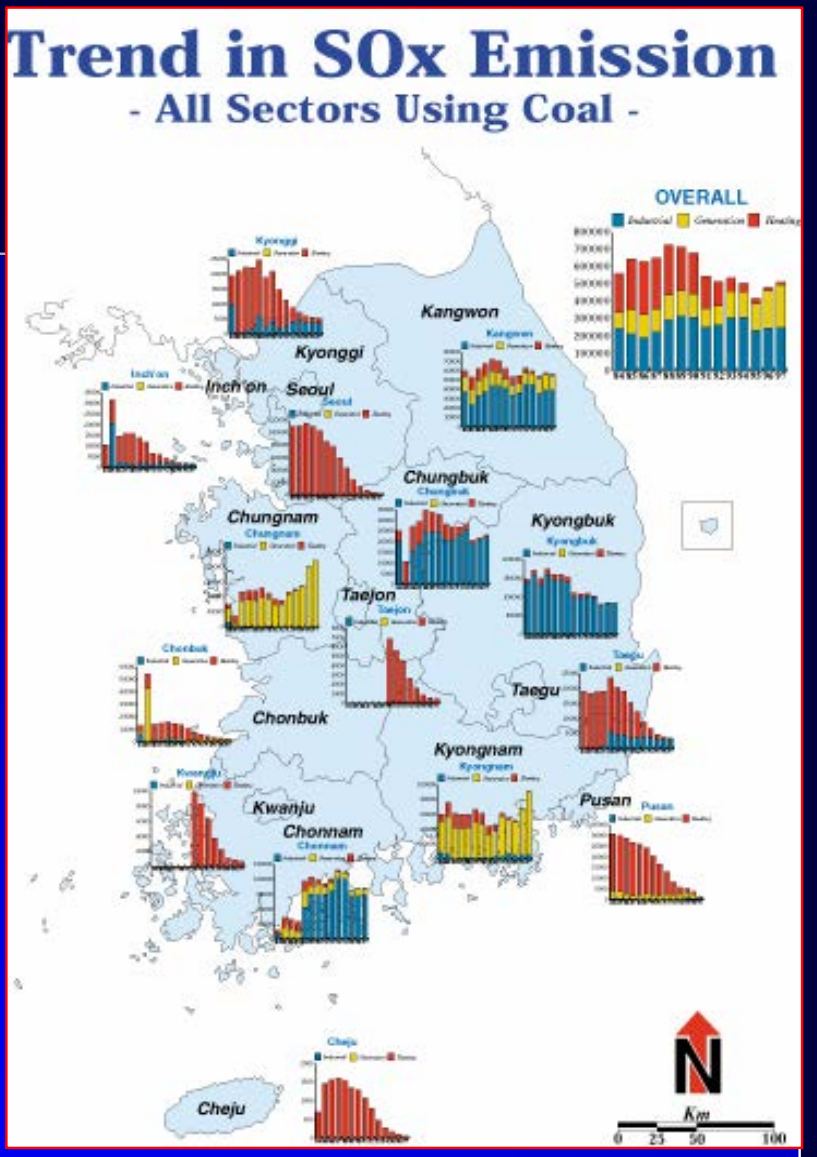
<Figure 1> So_2 emission from all sector

- In Korea, total 1,365 thousand tons of So_2 were emitted in 1997.
- 617 thousand tons were from industries & 354 thousand tons were from the combustion of coal and oil.
- Chung Nam &Kyung Nam provinces, much of So_2 were emitted.



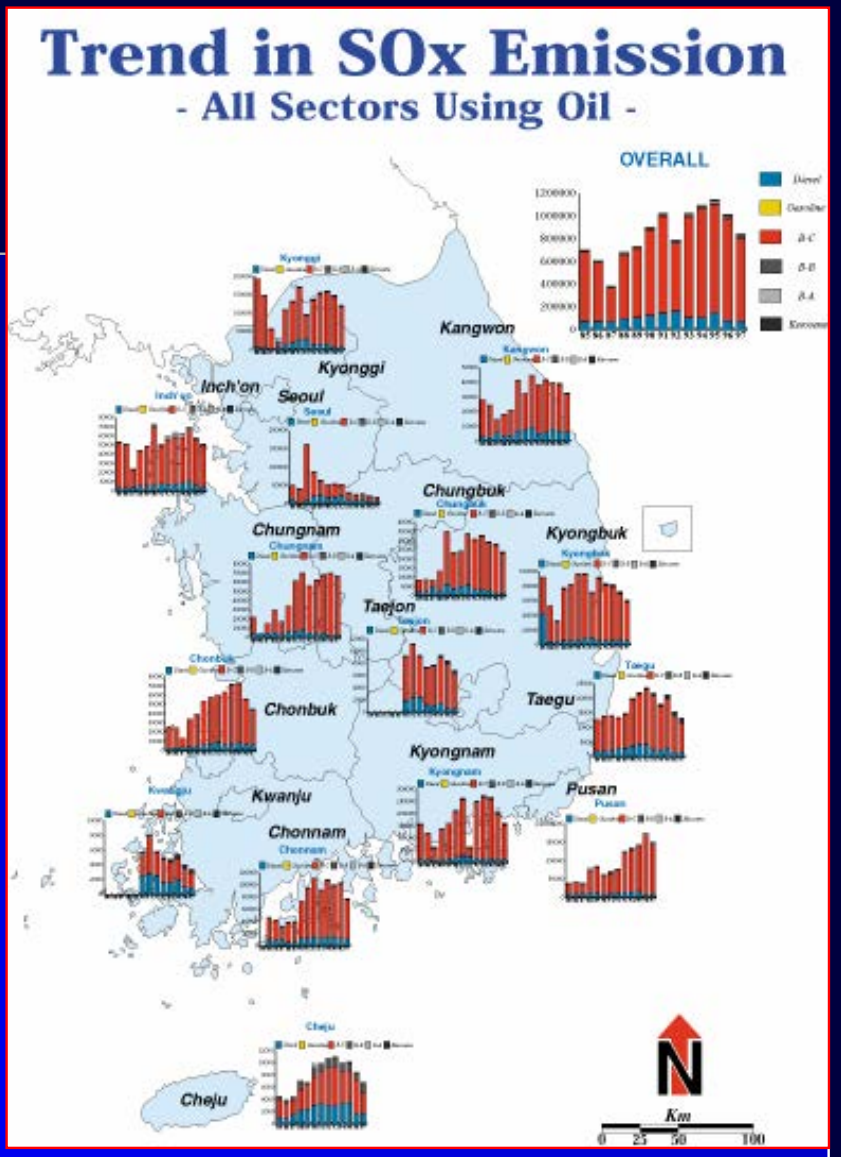
<Figure 2> So_2 emission from Coal

- Total So_2 emission from coal was 511 thousand tons.
- Chung Nam province, So_2 emission from power generation sector was 113 thousand tons.
- The same trend was observed in Kyung Nam province, the share of power generation sector was 16%.



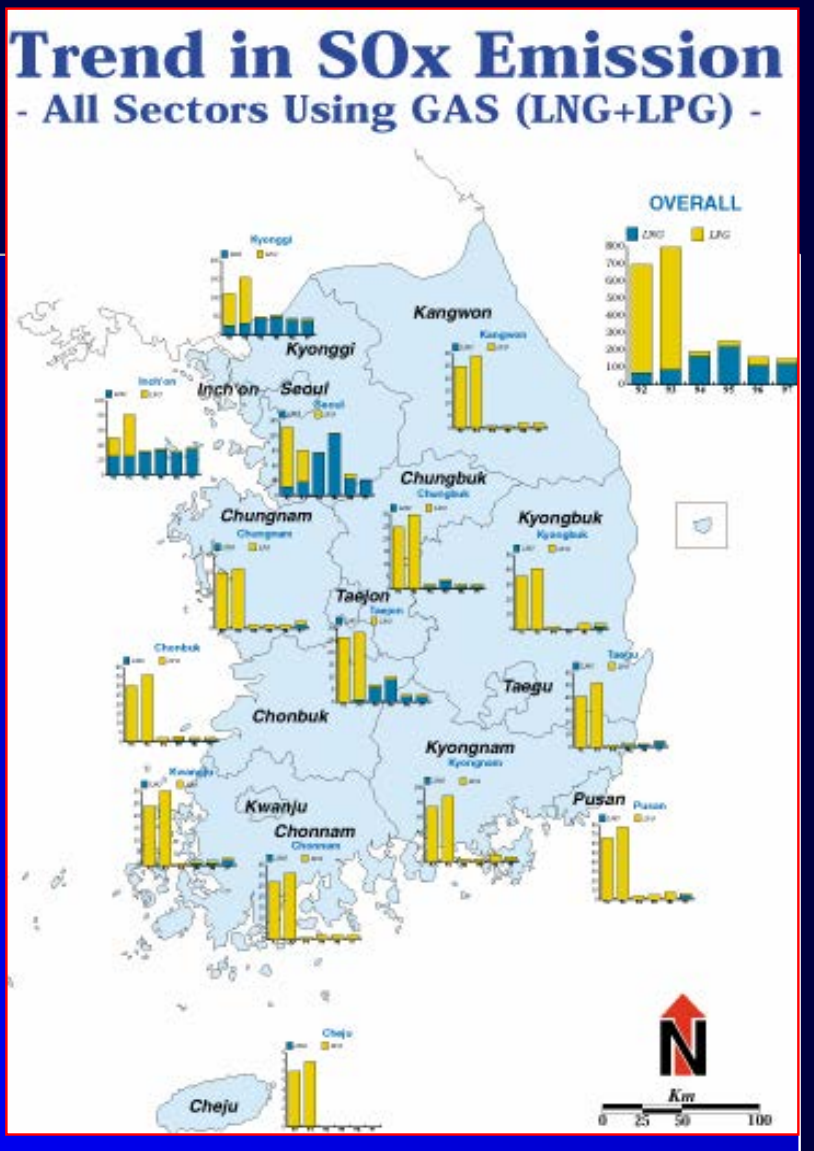
<Figure 3> So_2 emission from Oil

- Total So_2 emission from oil was 845 thousand tons.
- Most of So_2 emission came from B-C oil.
- Pusan city, So_2 emission from transportation sector was 135 thousand tons.



<Figure 4> So_2 emission from LNG

- Total So_2 emission was 152 tons.
- More than 75% of So_2 from gas combustion were emitted in Seoul, Inchon city & Kyunggi province, where it was mandatory to use gas in these areas.



5. Emission Inventory Map in Province Level (Cont'd)

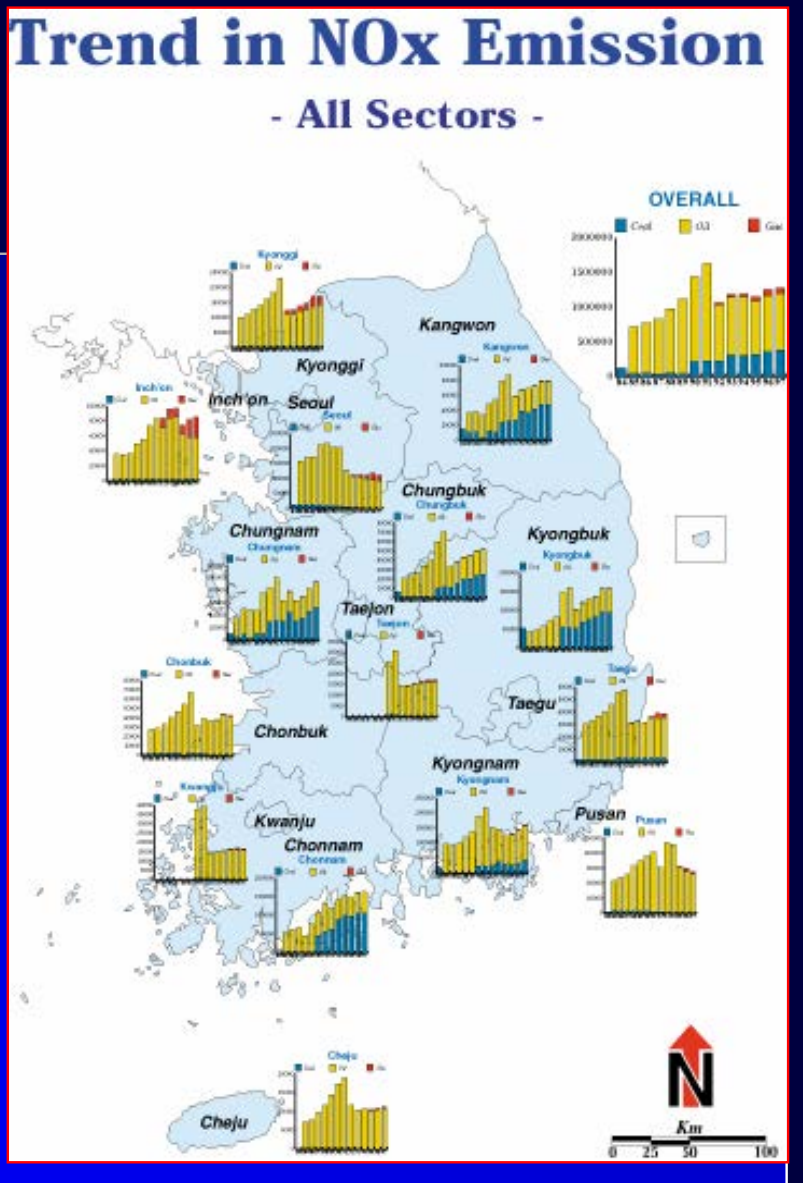
2) No_2 Emission

- No_2 emission in each province is shown at <Figure 5>-<Figure 8>.

  - <Figure 5> : No_2 emission from all sector
  - <Figure 6> : No_2 emitted from coal
  - <Figure 7> : No_2 emitted from oil
  - <Figure 8> : No_2 emitted from LNG

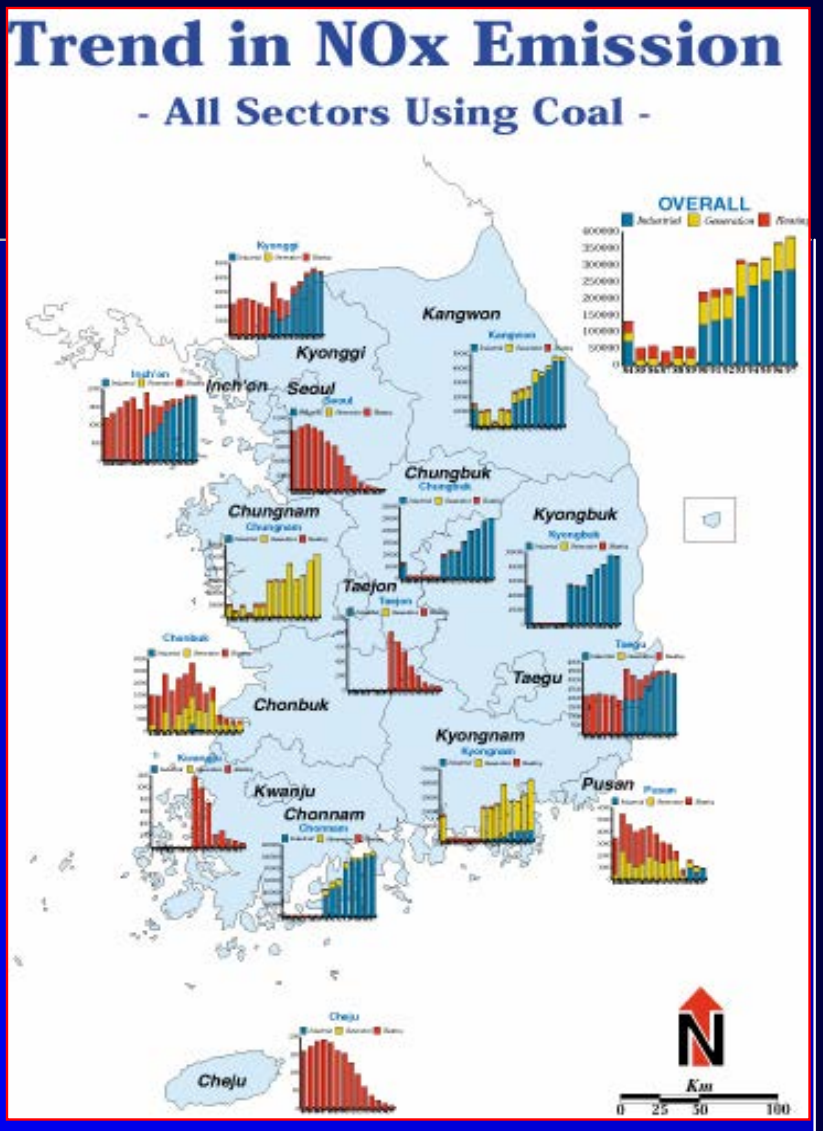
<Figure 5> No_2 emission from all sector

- In Korea, total 1,278 thousand tons of No_2 were emitted in 1997.
- 628 thousand tons were from transportation sector & 378 thousand tons were from industries and 203 thousand tons from power generation sector.
- No_2 emission from heating is spread in nationwide.



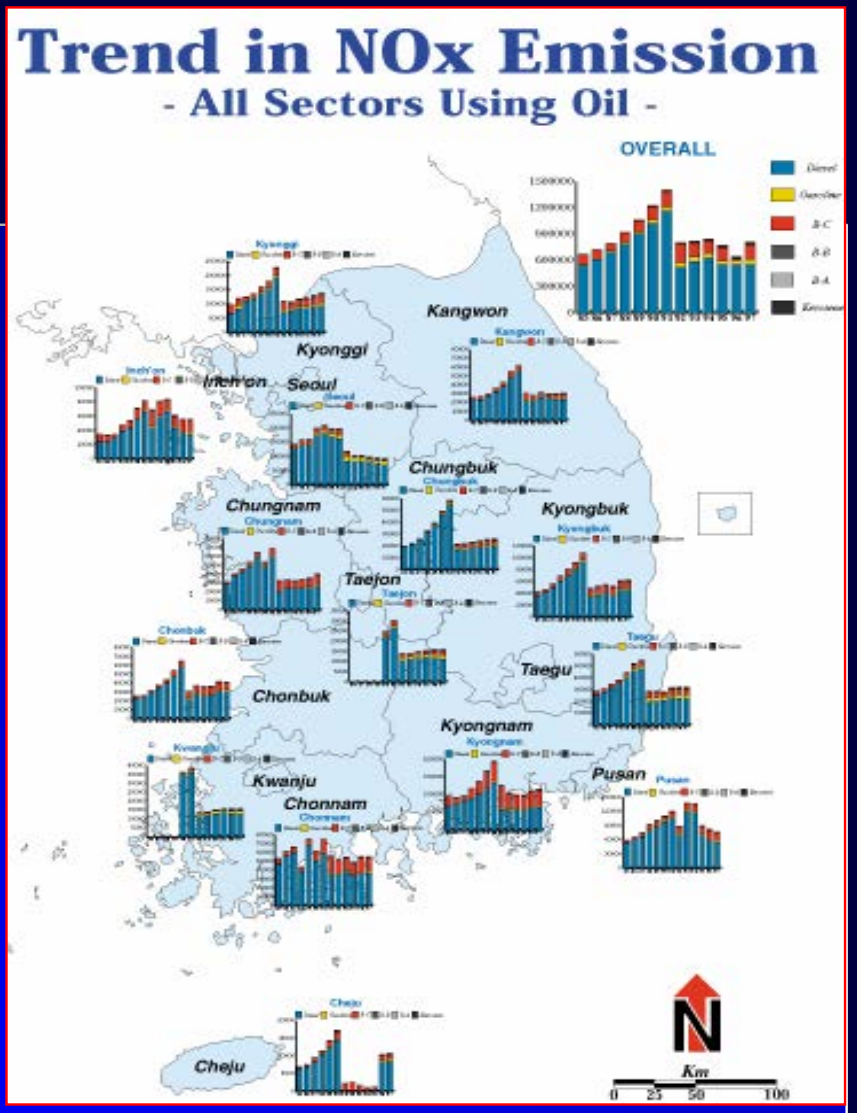
<Figure 6> No_2 emission from Coal

- Total No_2 emission from coal was 383 thousand tons.
- Jun Nam & Kyung Buk province, No_2 emission from industries took big share.



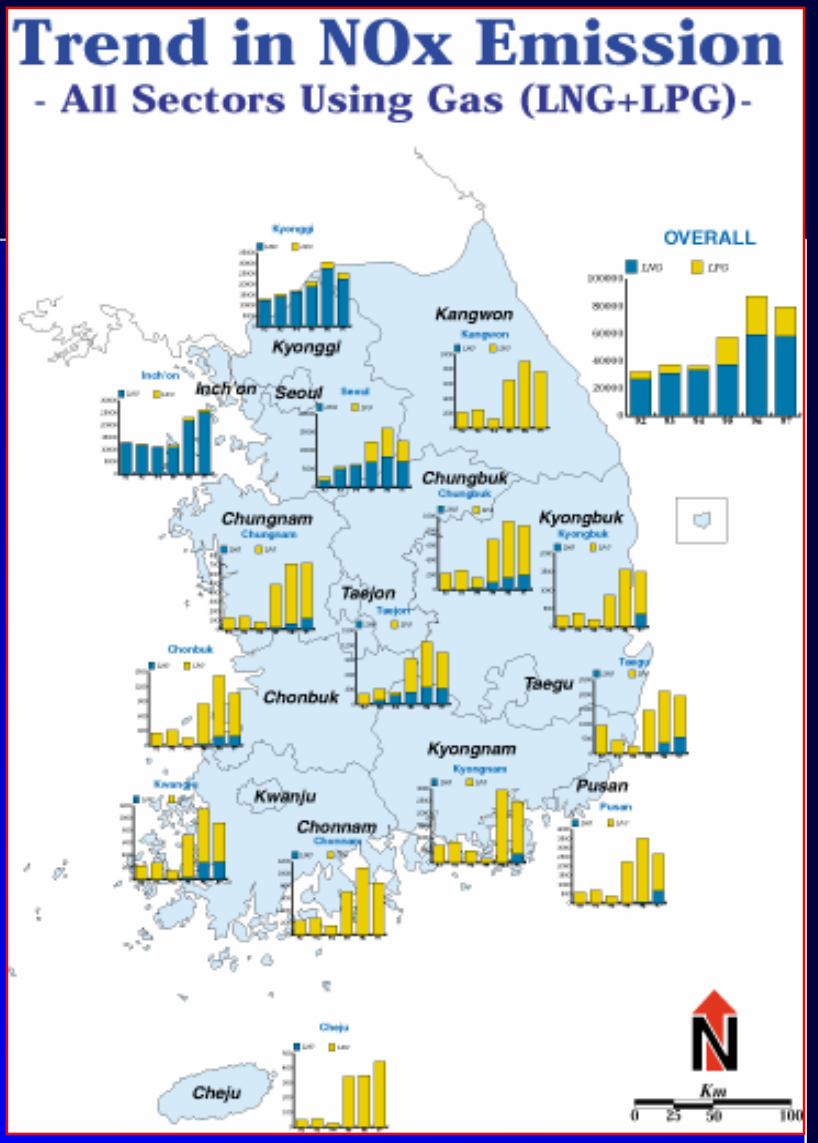
<Figure 7> No_2 emission from Oil

- Total No_2 emission from oil 815 thousand tons.
- Most of No_2 emission was concentrated around Seoul area and big cities.



<Figure 8> No_2 emission from LNG

- Total No_2 emission was 80 tons.
- Inchon city & Kyunggi province, 24 thousand tons and 20 thousand tons of No_2 were emitted, which covered in these areas More than 50% of total emission together.



6. Emission Inventory Map in Detailed Regional Level

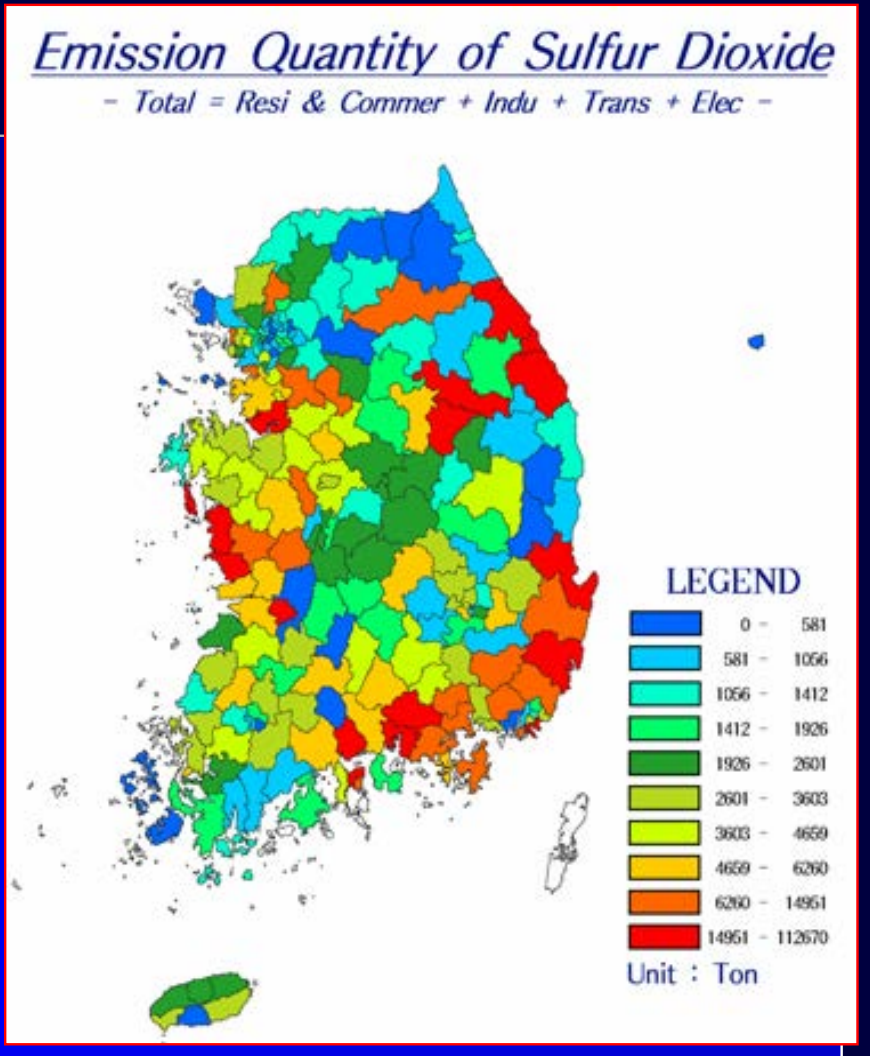
1) So_2 Emission

- So_2 emission in all 232 cities and districts at <Figure 9>-<Figure 13>.

  - <Figure 9> : So_2 emission from all sector
  - <Figure 10> : So_2 emitted from industries
  - <Figure 11> : So_2 emission from heating
  - <Figure 12> : So_2 emission from transportation
  - <Figure 13> : So_2 emission from power generation sector

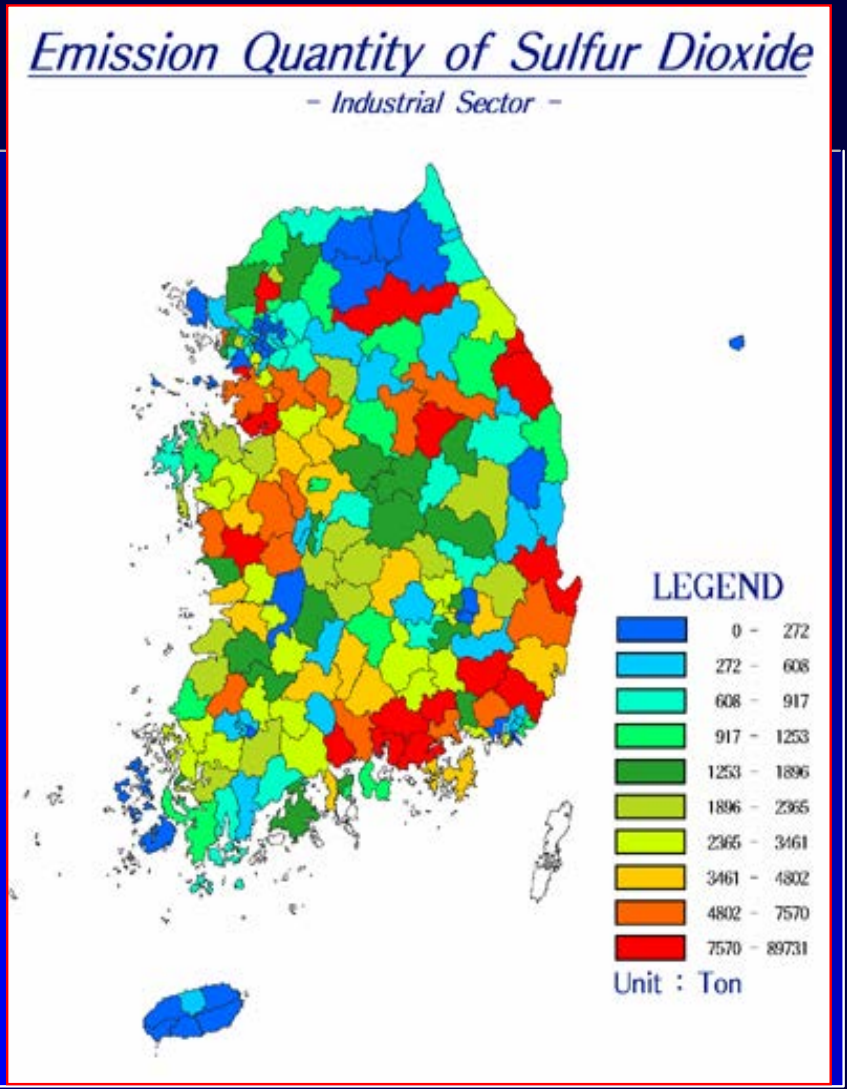
<Figure 9> So_2 emission from all sector

- Total 1,420 thousand tons of SO_2 were emitted in 1995.
- In Kwangyang city, Pohang city and Dong-gu in Pusan, Bohyung city, Ulsan city, SO_2 emission was severe, the share of which in each city was 7.9%, 7.7%, 6.3%, 5.1%, and 4.8%, respectively.



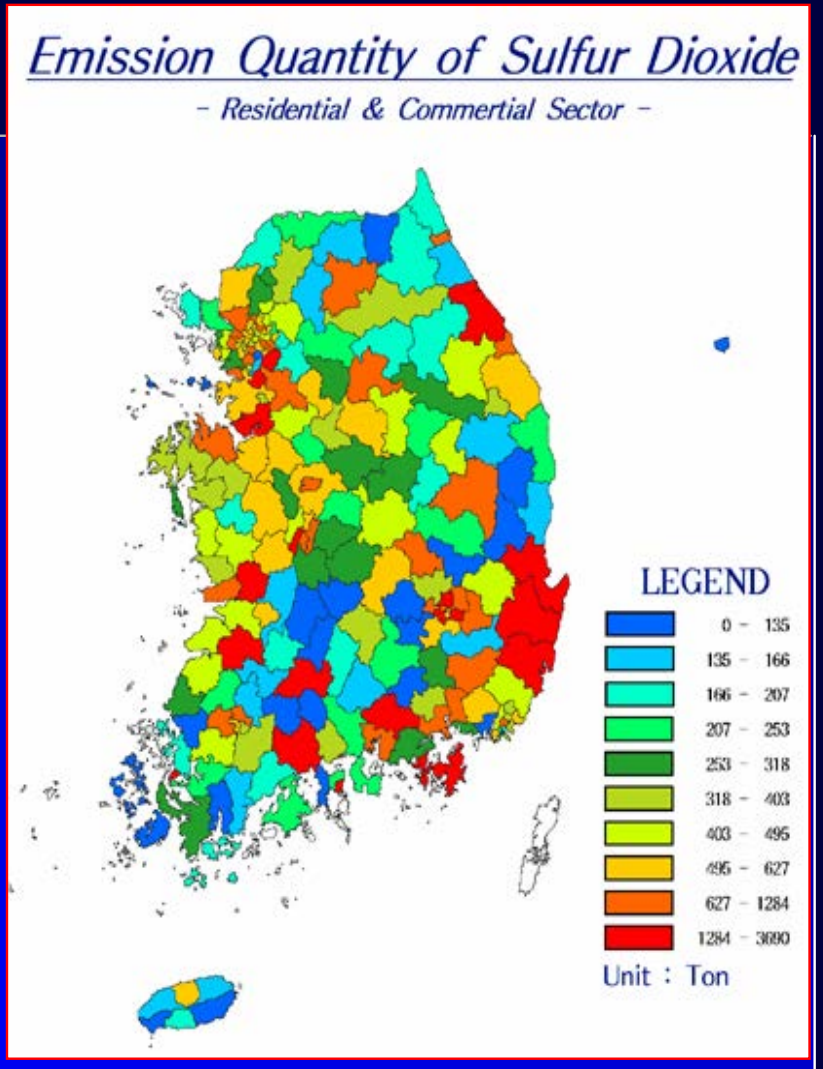
<Figure 10> So_2 emission from industries

- Total SO_2 emission from coal was 690 thousand tons, which covered 49% of total emission.
- It is worthwhile to note that in Kwangyang city and Pohang city, integrated steel making plants were located,
- In these two cities, 25% of total SO_2 emission from industries was covered.



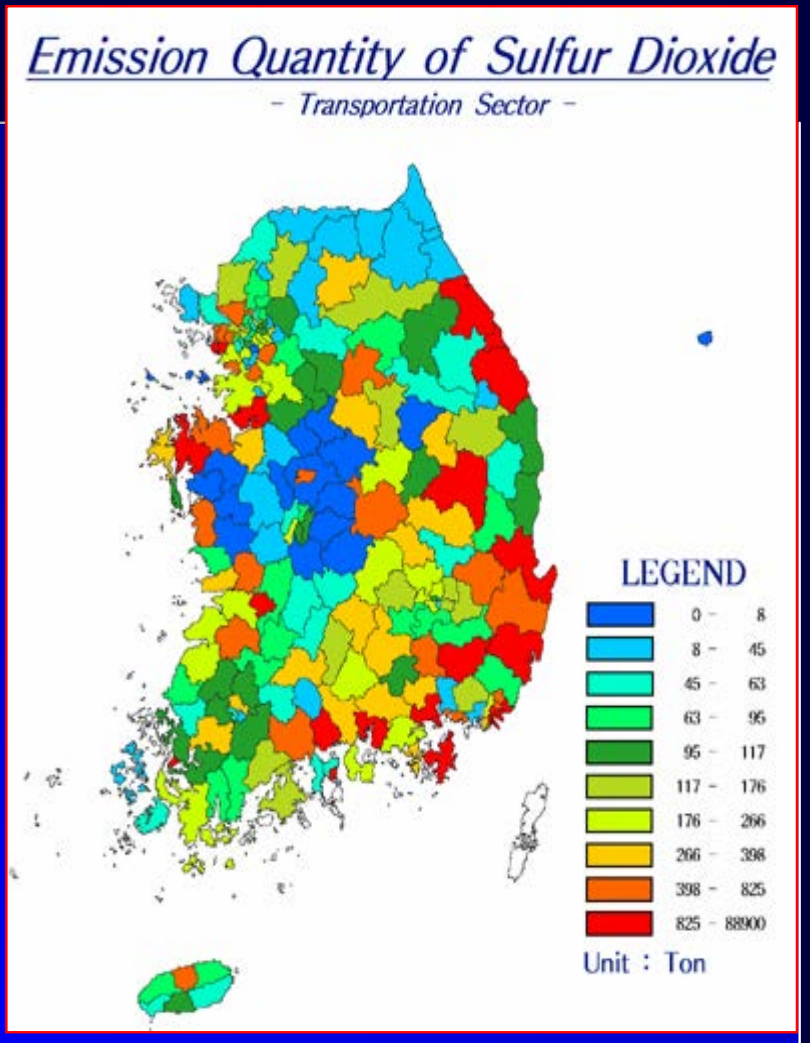
<Figure 11> So_2 emission from heating

- Total emission was 119 thousand tons, which shared about 8% of total SO_2 emission.
- It is observed that SO_2 emission from heating was relatively evenly spread to nationwide.
- In small cities, Jinju, Sooncheon, and Geoje, it was more severe, where fuel regulation has not been mandatory.



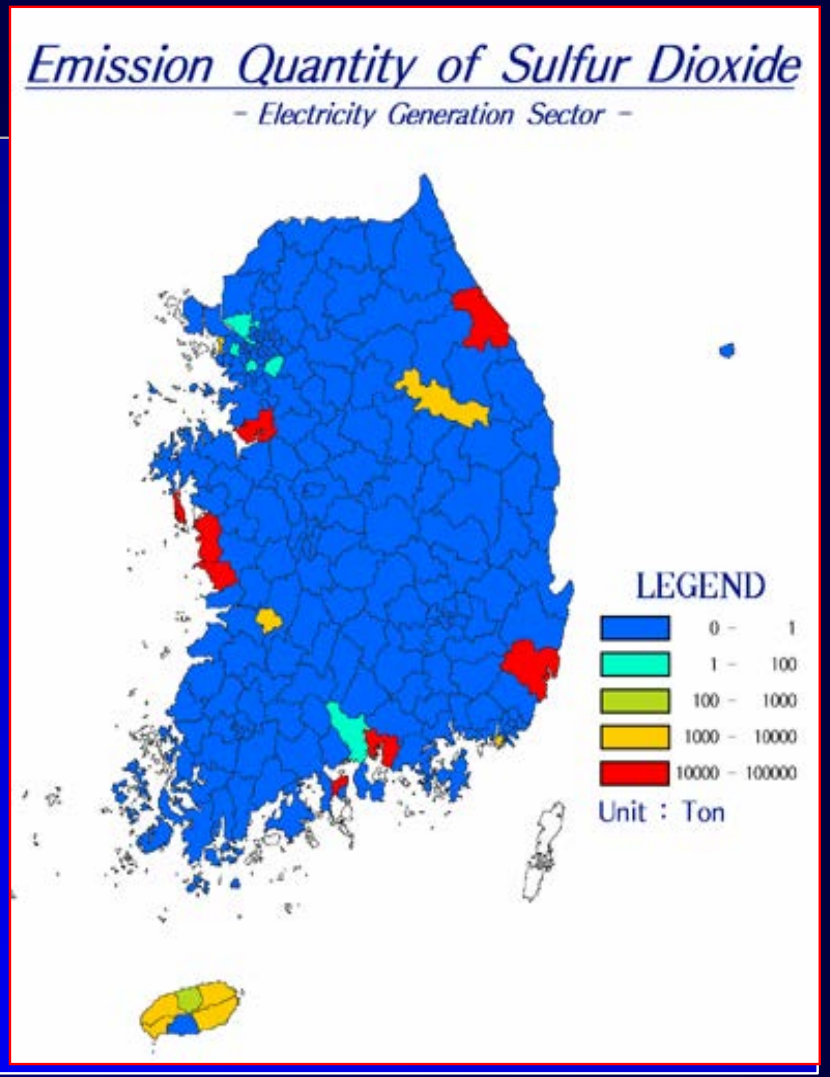
<Figure 12> So_2 emission from transportation

- Total emission in this sector was 322 tons, which covered about 23% of total emission.
- In Dong-gu of Pusan and Ulsan city, where important industrial seaports were located, SO_2 were emitted more than other regions.
- These two regions covered 36% of total emission in this sector.



<Figure 13> So_2 emission from power generation sector

- This sector shared about 20% of total emission, which was 290 thousand tons.
- The blue areas imply places where there were no power plants.
- In Boryung city, Pyubgtak city, Sacheon city and Ulsan city, where fossil fuel fired power plants were located, much of SO_2 emission is observed.



6. Emission Inventory Map in Detailed Regional Level (Cont'd)

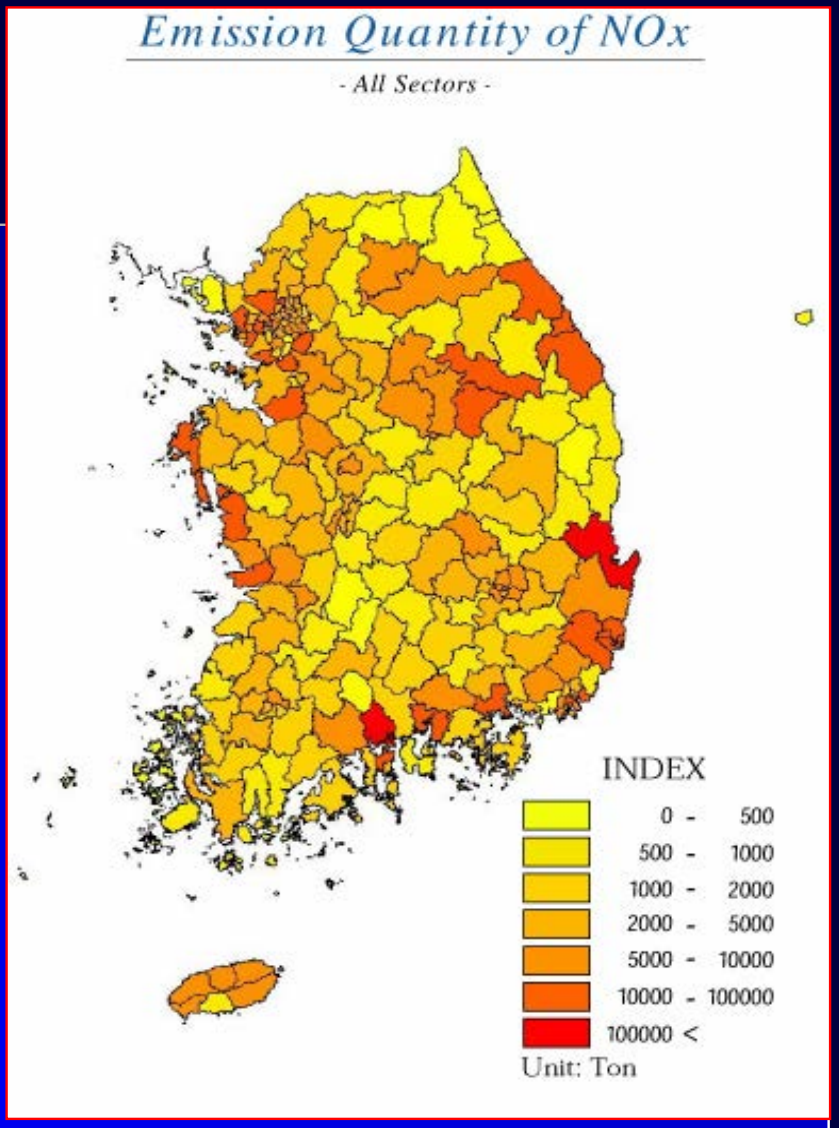
2) No_2 Emission

•No_2 emission in all 232 cities and districts at <Figure 14>-<Figure 17>

- <Figure 14> : No_2 emission from all sector
- <Figure 15> : No_2 emitted from transportation
- <Figure 16> : No_2 emission from heating
- <Figure 17> : No_2 emission from power generation sector

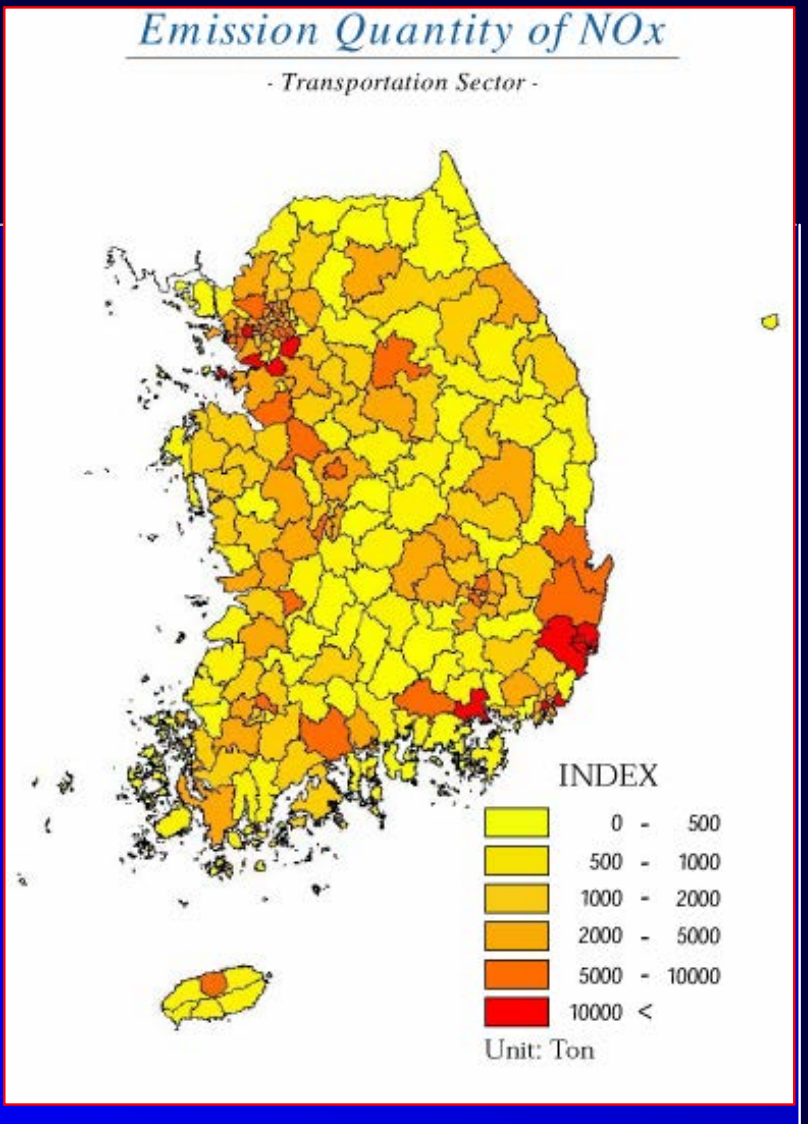
<Figure 14> No_2 emission from all sector

- In Korea, total 1,230 thousand tons of NO_2 were emitted in 1996.
- It shows the total emissions of NO2, Pohang city, and Kwangyang city emitted more NO2, since steel industries are located in two cities.



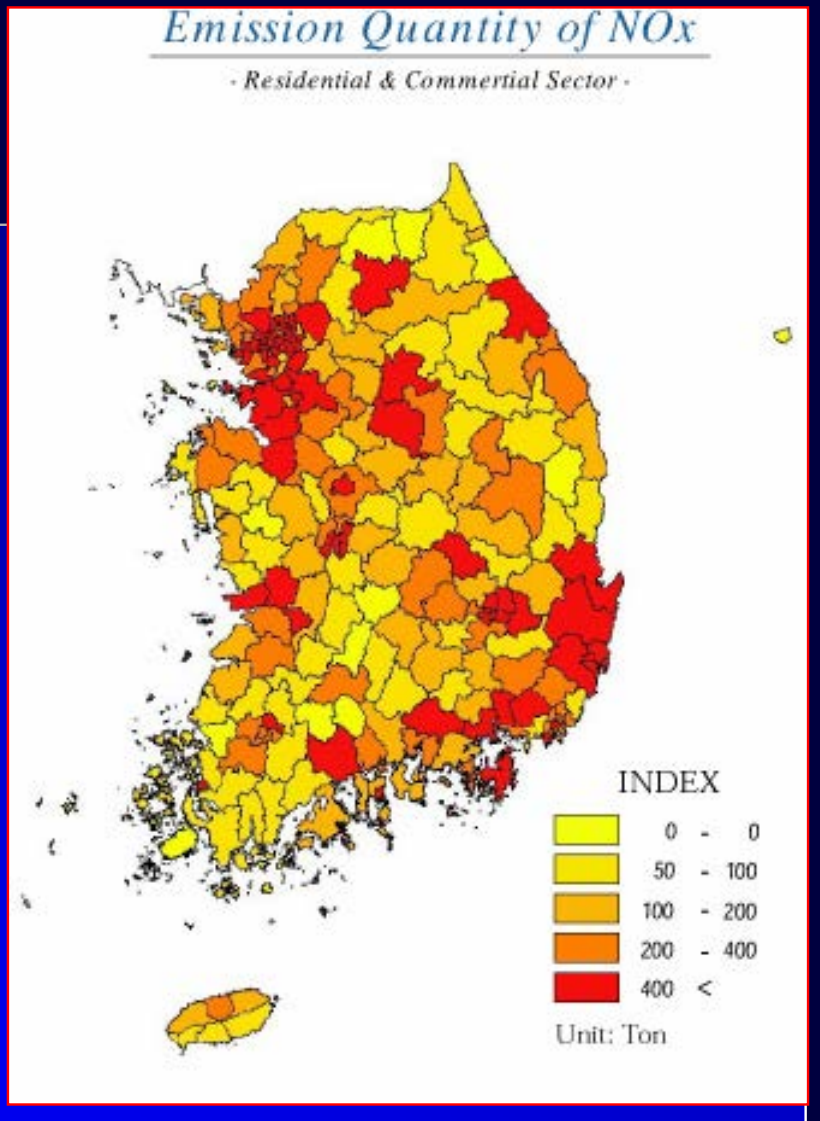
<Figure 15> No_2 emission from transportation

- This finding reflects the fact that Ulsan is an industrial city which has high rate of truck registered.
- Masan city, Suwon city, Sungnam city show similar trends.
- Kwangyang city and Pohang city, much of NO_2 was emitted like the case of SO_2 emission.



<Figure 16> No_2 emission from heating

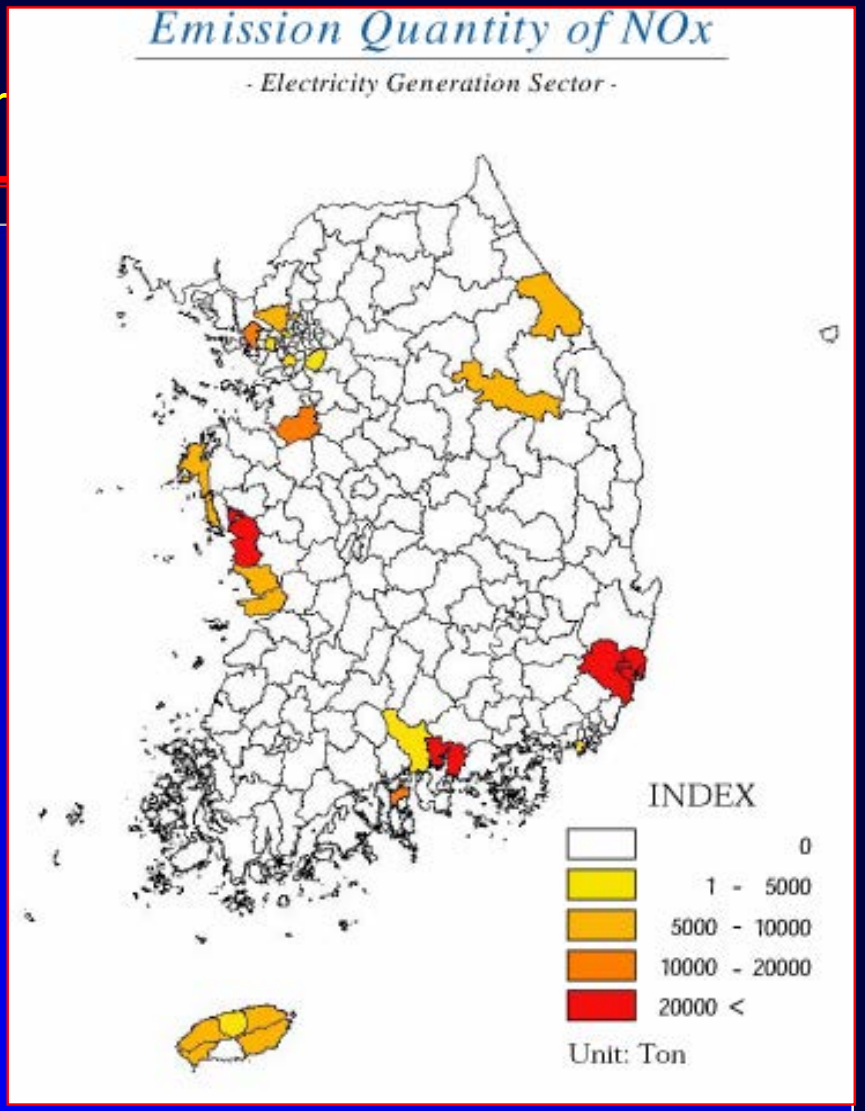
- Total emission was 70 thousand tons.
- It is also observed that NO_2 emission from heating was relatively evenly spread to nationwide.
- Ulsan, Suwon, Pohang, more emission of NO_2 was observed.



<Figure 17> No_2 emission from power generation sector

- This sector emitted 200 thousand tons, which was second smallest after heating sector.

- As the case of SO_2 emissions, in this figure, Boryung city, Pyugtak city, Sacheon city and Ulsan city, where fossil fuel fired power plants were located, much of SO_2 emissions are observed.



7. Conclusion and Future Study

- The purpose of this study is to identify SO_2 and NO_2 emission inventories by detailed regional level to tackle the issue of 'Acid Rain.
- Basic inventory GIS will provide fundamental bases for this analysis.
- First, we develop GIS of SO_2 & NO_2 emission inventories, using data of Ministry of Environment,from 1984 to 1997 at province level.
- Total SO_2 emission in 1984 was 1,226,000 tons and 1,356,000 tons in 1997;final energy consumption was increased from 44.8 million TOE to 139.6 million TOE during the same period. This is mainly due to the fuel substitution to lower sulfur oil and natural gas.
- Total NOx emission in 1984 was 756,000 tons and 1,278,000 tons in 1997, lower than the growth rate of final energy demand; NO_2 emission continuously increased, compared with the trend of SO_2 emission.

7. Conclusion and Future Study(Cont'd)

- The estimation of SO_2 emission inventory in detailed regional level (cities and districts) is proper enough by the method developed here.
- Emission from cement & steel industries and power generation sector is directly based on the emission data of each city and district.
- Emission from other sector is also based on currently available data, which seems to be reasonable.
- However, due to the limitation of obtaining data on large point, it is possible to overestimate or underestimate the emission from large points.

7. Conclusion and Future Study(Cont'd)

- For further examination on identifying emission sources in detailed regional level, followings are necessary.

First, in industrial sector, it is necessary to separate large point sources where the capacity of boiler is larger than 100 tons. The data for these sources are available internally in Ministry of Environment for environmental management.

Second, in power generation sector, the desulsurization facilities will be installed at 17 power plants from this year. Expected SO_2 emission will be reduced drastically in this sector. Hence, it is necessary to take the change in this sector into accounts for further study.

7. Conclusion and Future Study(Cont'd)

- For NO_2 emission, there is difficulty to estimate it by detailed regional level due to the following reasons.

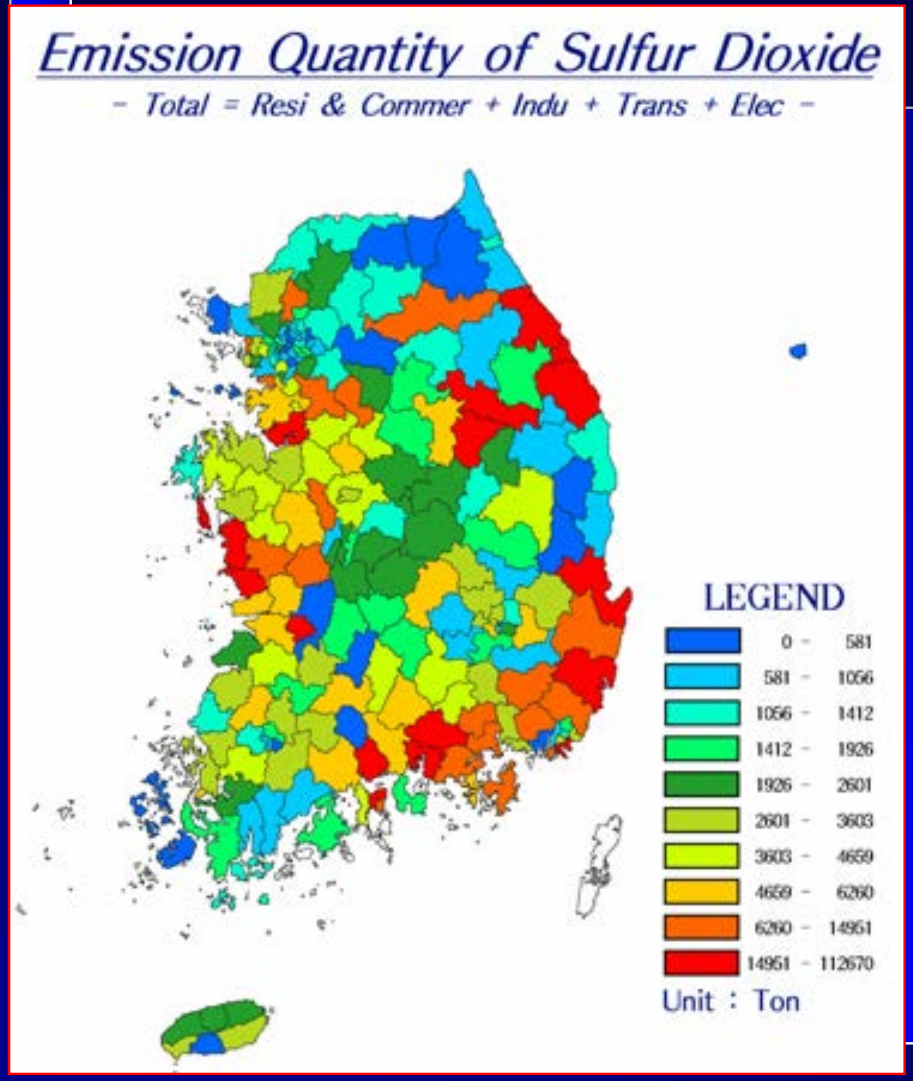
First, in Korea, the area of city and district is relatively narrow, so that much of moving pollutant sources is utilized beyond the city and district.

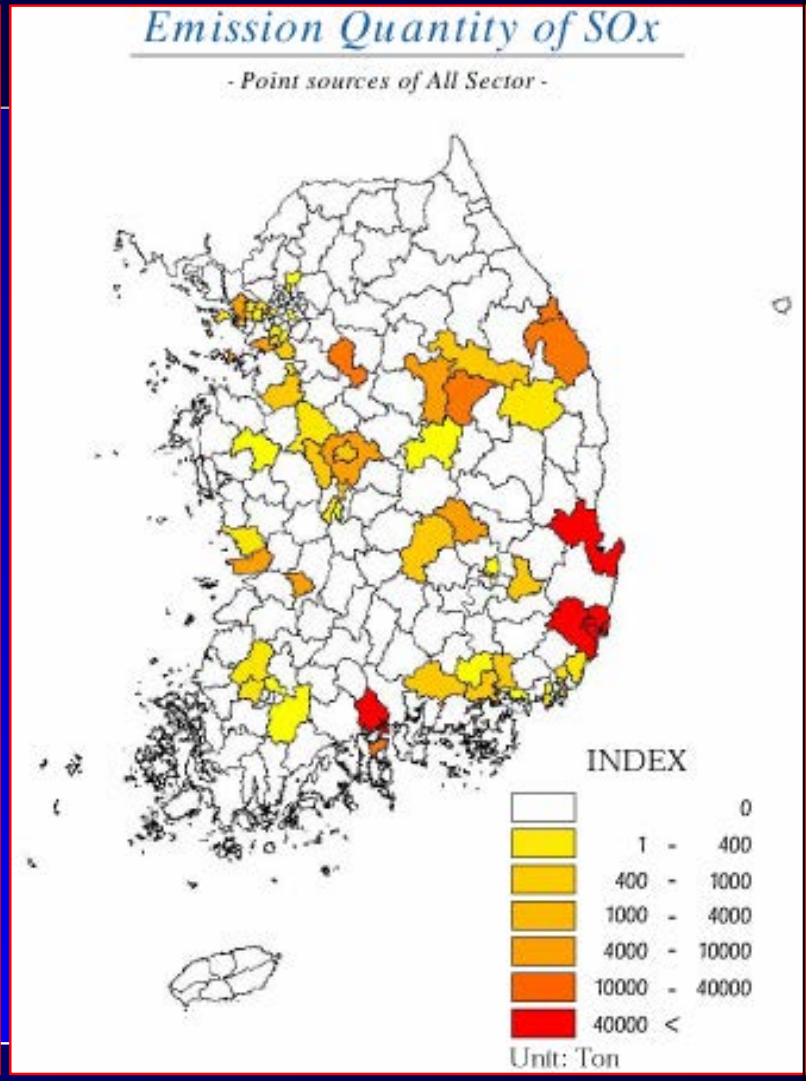
Furthermore, the basic data such as vehicle distance per day by transportation mode is not available at detailed regional level.

Hence, it is considered to develop a method to estimate NO_2 emission by detailed regional level like in SO_2 emission.

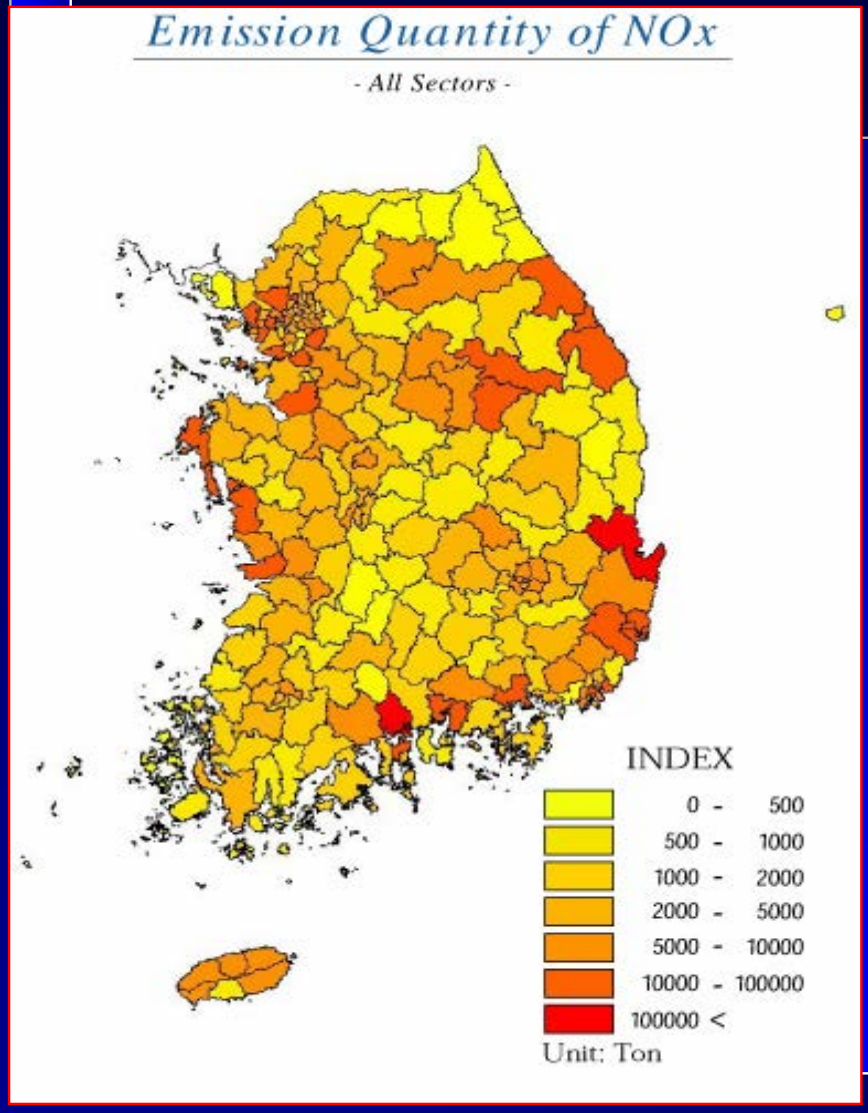
All Sectors of SO_2

Point sources of all Sectors





All Sectors of NO_2



Point sources of all Sectors