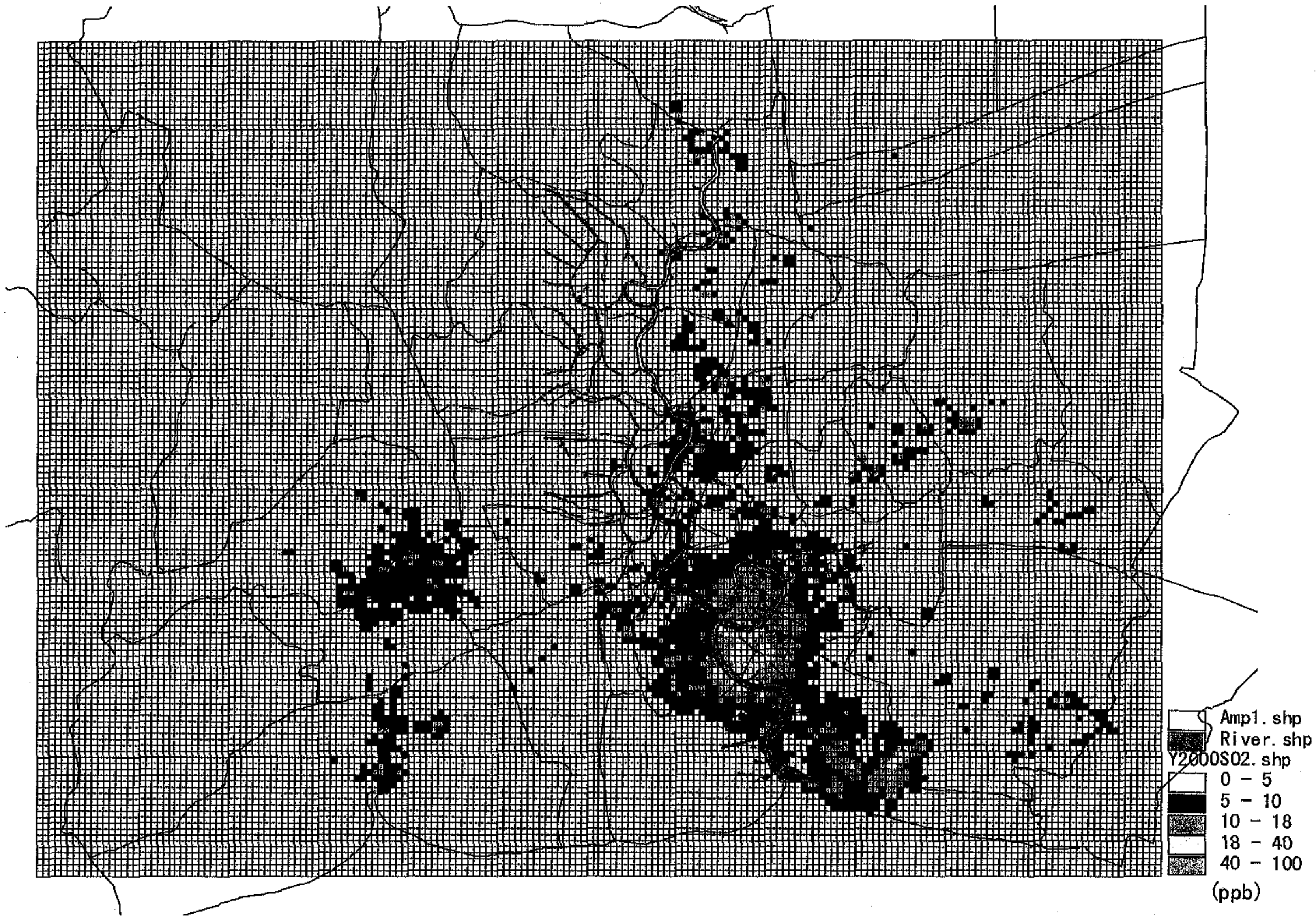

Figure 6.2.8.2 SO2 Concentration Map for the Year 2000 in the BMR

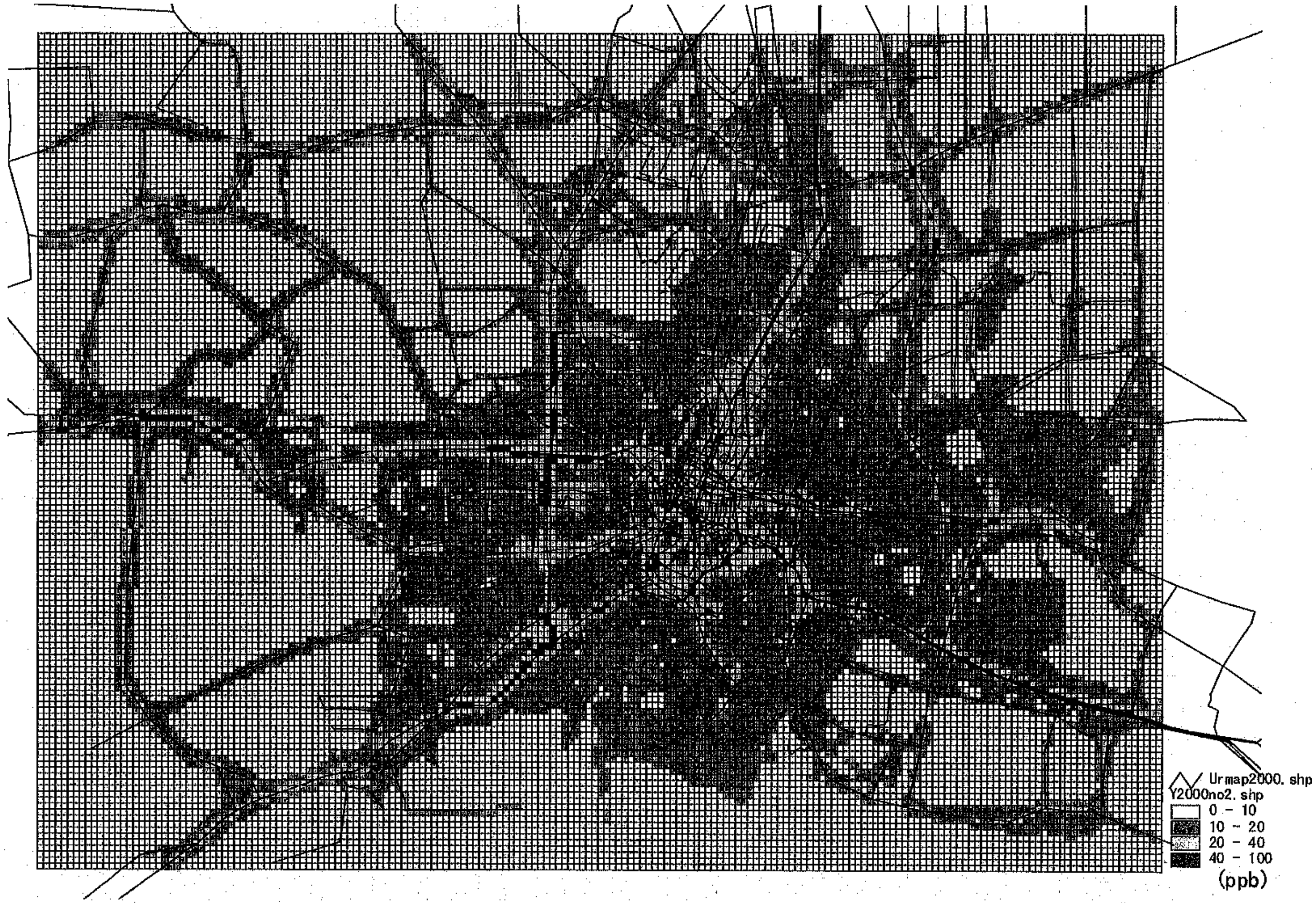

Figure 6.2.8.3 NO2 Concentration Map for the Year 2000 in the BMR

6.2.9 Model Simulation for the Year 2011

6.2.9.1 Simulation Conditions for the Year 2011

The meteorological conditions and model parameters are the same as the ones for the year 2000. The pollutant emissions of mobile and stationary sources for the year 2011 in BMR are estimated in chapters 3 and 4.

6.2.9.2 Comparison of Simulation Results with the Annual Standard

Comparison with the year 2011 simulation result with the ambient annual standard of Thailand and the WHO standard for each grid is shown in Table 6.2.9.1. The NO2 annual standard of Thailand is used as the target annual standard (see Section 7.2.6). 3 grids of SO2 and 60 grids of NO2 exceeded the Thailand standard. 230 grids (0.8%) of SO2 and 2127 grids (8.1%) of NO2 are exceeded the WHO standard. The maximum of SO2 and NO2 is 72.5ppb and 54.3ppb. The number of NO2 which exceeded the calculation grids is more than SO2, but the NO2 maximum is lower than SO2.

Table 6.2.9.1 Comparison Simulation Results with the Ambient Annual Standard

Item	Standard(Number of Exceed Grid / Total Number of Grid)	
	Thailand (SO2, NO2 : 40ppb)	WHO (SO2 :18ppb, NO2 : 20ppb)
SO2	3/26320	230/26320
NO2	60/26320	2127/26320

*NO2 Thailand Annual Standard is used as the target annual standard

6.2.9.3 Simulation Results for the Year 2011

The SO2 and NO2 concentration maps for the year 2000 is shown in Figure 6.2.9.1 and Figure 6.2.9.2. Compared with the year 2000 simulation, 18ppb exceed the calculation grids of the SO2 concentrations in the year 2011 increased. The NO2 high concentration area appeared around the new ring roads in the year 2011. However, on the whole the 20ppb exceed calculation grids of the NO2 concentration decreased.

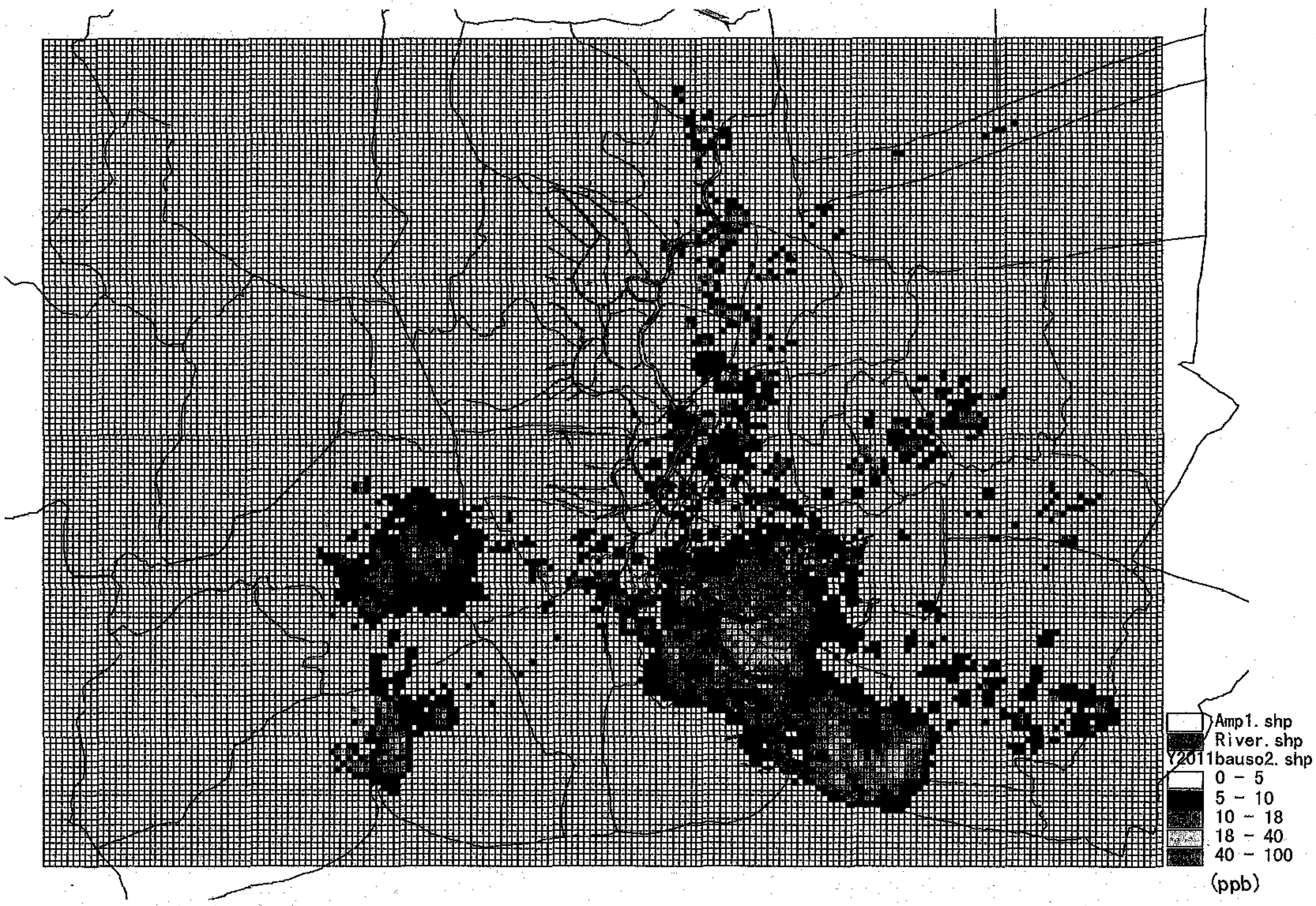

Figure 6.2.9.1 SO2 Concentration Map for the Year 2011Bau in the BMR

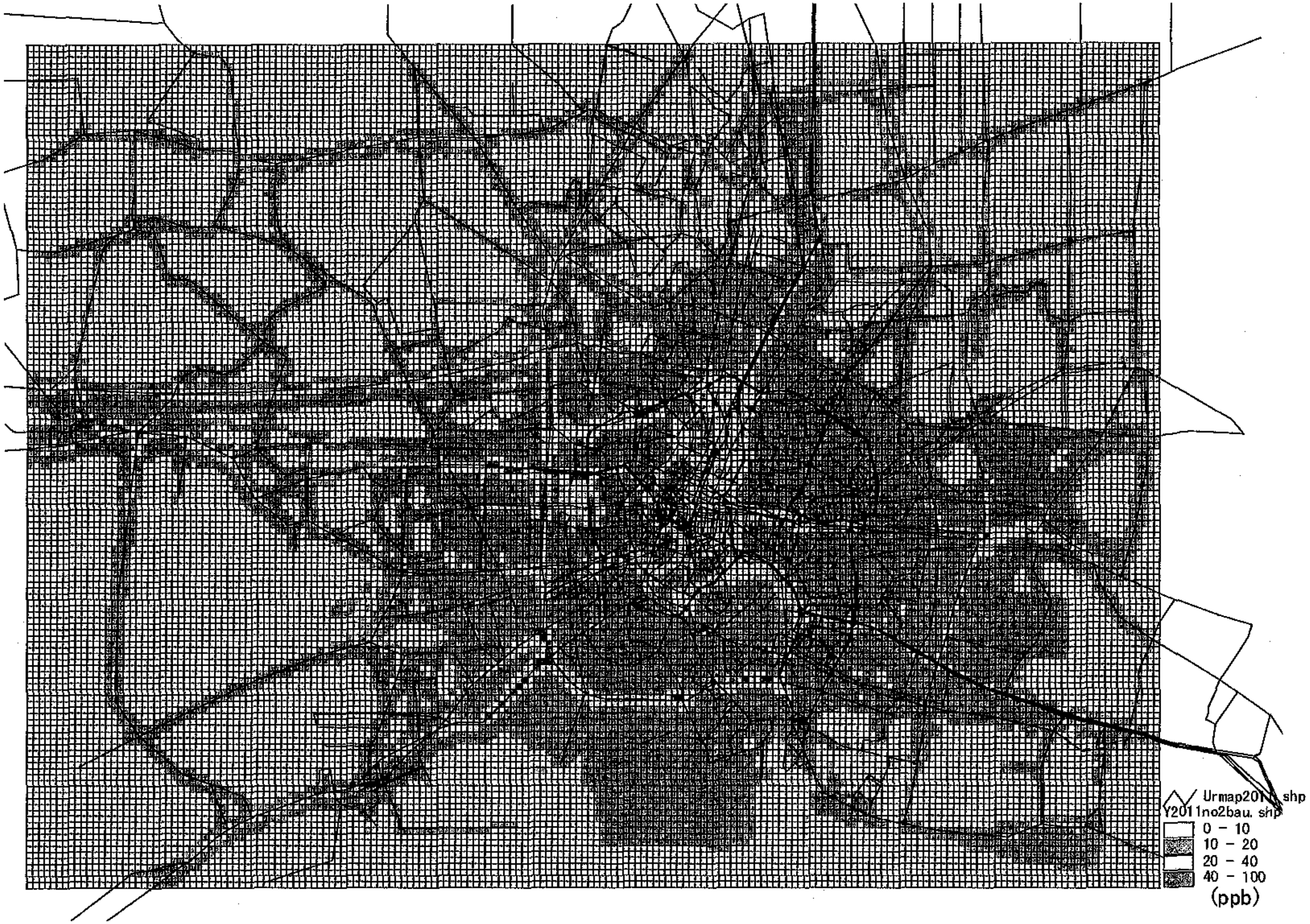

Figure 6.2.9.2 NO2 Concentration Map for the Year 2011Bau in the BMR

6.3 Technology Transfer on Simulation Models

6.3.1 Overview of Technology Transfer

Technology transfers are conducted for both the simulation models, ATMOS2 and Airviro.

For the ATMOS2 simulation, technology transfers are divided into four categories of meteorological pre-processors, emission source pre-processors, ATMOS2 simulation program, and results displaying programs. Basic understandings of the computer languages of FORTRAN and ArcView script are necessary for these technology transfers, and the basics of these languages were explained at first and trained throughout the course of developments of pre-processors etc.

Technology transfer for Airviro has two main fields such as emission source pre-processors and the Airviro system. Airviro is the integrated system and meteorological input data are obtained via on-line module and it also has results displaying functions. In a sense, meteorological pre-processing and results displaying are already included in the existing Airviro system. The technology transfer of pre-processors is composed of the basic understanding of FORTRAN programs and respective inventory preparations. Technology transfer of the Airviro system is composed of system operations, understanding of dispersion module and model tuning. Training items for the target persons are shown in Table 6.3.1.1.

The administration staffs for the simulation are members of PCD. The resource persons of simulation are three members of SECOT Co., Ltd. who are the support group for administration staff.

Table 6.3.1.1 Training Items

Training Items		Target Person	
		Administration Person	Resource Person
Basics			
System Operation	Linux OS for ATMOS2	○	○
	UNIX OS for Airviro	−	−
Computer Language	FORTRAN Language	○	○
	ArcView Script	○	○
ATMOS2			
Meteorological Pre-Processor	Local Rain Data Compilation	△	○
	Local and NCEP Data Exchange	△	○
Emission Source Pre-Processor	Point Sources Processing	△	○
	Line Sources Processing	△	○
	Area Sources Processing	△	○
ATMOS2 Simulation Model	Algorithm and Theory of ATMOS2 Model	○	△
	Regional and Urban Grid Setting	○	△
	Model Tuning	○	△
	Evaluation of Simulation Results	○	△
Airviro			
Emission Source Pre-Processor	Point Sources Conversion for Database	△	○
	Line Sources Conversion for Database	△	○
	Area Sources Conversion for Database	△	○
Airviro Simulation	Airviro System Operation	−	−
	Theory of Grid Dispersion Module	○	△
	Model Tuning	○	△
	Evaluation of Simulation Results	○	△

○ : Necessary
△ : Desirable
− : Not necessary (target person is familiar with the item)

6.3.2 Basics

6.3.2.1 System Operation

ATMOS2 is operated on the Linux operating system and Airviro on the UNIX system. As the administration staff and one of the resource persons have fully mastered the UNIX system operation, technology transfer on the operating system is only for the Linux system. Furthermore, the Linux operation is very similar to the UNIX operation and it is very easy for the target persons to learn the Linux system operation.

6.3.2.2 Computer Language

The languages used in this project are FORTRAN and ArcView script. After the short lectures on the languages, some sample programs were explained and the target persons were introduced to write useful programs like pre-processors etc.

6.3.3 Technology Transfer of ATMOS2

6.3.3.1 Meteorological Pre-Processor

Meteorological pre-processing is divided into two steps. .

- The first step is the compilation of local rain data into the grid system.
- The second step is exchanging the NCEP grid values around Thailand with the local rain data.

These steps are conducted by the FORTRAN programs prepared as meteorological pre-processors.

6.3.3.2 Emission Source Pre-Processor

1) Method of Pre-processing

The inventory data files of the Study Team are processed with the FORTRAN programs and ArcView scripts (programs) and finally compiled into ATMOS2 input format.

2) Training of ArcView Script

The ArcView script is taught to the target persons mainly accompanied with the development of the ATMOS2 emission source pre-processors. The Study Team trained resource persons to understand the sample ArcView Scripts and introduced exercises to improve the scripts. The training has three steps as follows.

- The first step is the explanation of the sample scripts to the target persons.
- The second is exercises adding some functions to the sample scripts.
- The third is to make a manual and explanation about the pre-processors.

3) Point Sources

The point sources processing is as follows.

- Large stationary point sources compiled as Excel file format are converted to text file format.
- The text file data are processed with the ArcView scripts and compiled into the decimal degree grid system as intermediate format.

Technology transfer is conducted by the exercise using the pre-processing scripts and actual data.

4) Line Sources

The line sources processing is as follows.

- Line sources like major road traffic etc. are made as ArcView shape format.
- The shape format data are processed with ArcView scripts and compiled into the decimal degree grid system as intermediate format..

Technology transfer is conducted by the exercise using the pre-processing scripts and actual data.

5) Area Sources

The area sources processing is as follows.

- The total province pollutant emissions etc. are made as Excel format.
- The emission amount data are processed together with the province shape data etc. by ArcView script into the decimal degree grid system.

Technology transfer is conducted by the exercise using the pre-processing scripts and actual data.

6) Compilation as ATMOS2 Input Format

Point, line and area sources are finally summed into the decimal grid system and compiled as ATMOS2 format.

6.3.3.3 ATMOS2 Simulation Model

1) Algorithm and Theory of the ATMOS2 Model

- Firstly, the algorithm and theory of the ATMOS2 Model were explained several times at technical meetings, steering committee meetings, and seminars.
- Secondly, more detailed lectures were conducted to the target persons.
- Thirdly, explanations of the FORTRAN source code and some related exercises with the source code were conducted.

2) Regional and Grid System Setting

The parameter settings for the regional grid and urban grid system were explained, and some exercises for parameter settings were conducted.

3) Model Tuning

The Study Team trained administration persons and resource persons for model tuning by OJT training. The technology transfer of the model tuning items is as follows.

- Checking of meteorological and pollutant emission data
- Understanding of the regional and urban grid systems
- Sensitivity analysis of wet deposition coefficient
- Sensitivity analysis of precipitation data
- Evaluations of simulation results
- Simulations for the year 2000, the year 2011 BaU and the year 2011 with control

6.3.3.4 Results Displaying

Simulation results are displayed with ArcView scripts and the figures displayed are as follows.

- Annual Precipitation Map
- Pollutant Emission Map
- Sulfur Deposition Map
- SO2 Concentration Map
- Critical Load Map
- Exceeding Ratio Map

Technical transfer is conducted by the processing of actual data.

6.3.4 Technology Transfer of Airviro

6.3.4.1 Emission Source Pre-processor

The Study Team has trained administration staffs and resource persons to prepare the Airviro emission database.

1) Method of Pre-processing

The inventory data files of the Study Team are converted to Airviro pollutant emission databases (EDB) with the FORTRAN programs and ArcView scripts (programs).

2) Training of FORTRAN Language

The FORTRAN language is taught to the target persons mainly accompanied with the development of the Airviro emission source pre-processors. The Study Team trained resource persons to understand the FORTRAN language. The training has four steps as follows.

- The first step is to understand FORTRAN basic grammar.
- The second is to prepare some FORTRAN programs for reading text files.
- The third is to prepare conversion FORTRAN programs for Road.txt and Roadtype.txt.

The mobile databases are composed of the Road.txt database and the Roadtype.txt database. The Road.txt database includes information such as locations, traffic volumes, pattern numbers, road names and traffic speeds. The Roadtype.txt database includes information such as hourly vehicle patterns and the vehicle type composition of traffic vehicles.

- The fourth is to import the Road.txt and Roadtype.txt into Airviro system for checking the FORTRAN programs and restrictions of the Airviro database.

3) Point Sources

Technology transfer for point sources is as follows.

- Airviro point source database format
- Conversion of ArcView files into text files
- Conversion of Excel files into text files
- Preparation of the FORTRAN program for area sources
  Types of point sources
  Preparation of inventory data
  Excel file => Airviro format file

4) Area Sources

Technology transfer for area sources is as follows.

- Airviro area source database format
- Conversion of ArcView files into text files
- Conversion of Excel files into text files
- ArcView into area sources by script
- Preparation of the FORTRAN program for area sources
  Summarize program
  Conversion program for the Airviro database

5) Line Sources (Main Roads)

Technology transfer for line sources is as follows.

- Lecture of the Airviro line sources database format
- Conversion of ArcView files into text file
- Preparation of the FORTRAN program for line sources
  Preparation of the road database
  Preparation of the roadtype database
  Preparation of the emission factor

6.3.4.2 Airviro Simulation Model

1) Airviro System Operation

The administration person is familiar with the Airviro system operation. Also, one of the resource persons used the Airviro system as a PCD member. They trained two resource persons to handle the Airviro system through the OJT training.

2) Dispersion Module

The Study Team trained the administration person to understand the dispersion module through OJT and preparation of the seminar. The administration person has made a presentation for the second seminar and the international seminar.

3) Model Tuning

The Study Team trained the administration persons and resource persons for model tuning by OJT training. Technology transfer of the model tuning items are as follows.

- Preparation and characterization of the monitoring data
- Evaluation of the monitoring stations
- To understand the method of the NO_2 statistical model and SO_2 conversion
- Vertical Layer Setting
- Road Emission Heights and Calculation Height Settings
- Emission Source Type Categorization

- Confirmation method of the mobile and stationary source emissions
- Evaluation of simulation results
- Simulations for the year 2000, the year 2011 BaU and the year 2011 with control

Charpter 7

Evaluation of Acid Deposition and Air Quality

7. Evaluation of Acid Deposition and Air Quality

Acid deposition and ambient air pollution data are collected and analyzed. Socio-economic conditions are analyzed and inputted into inventory analyses. Inventories for stationary and mobile sources, for the year 2000 and 2011, are prepared. The inventory for the year 2011 depends on the business as usual case. After the validation of model by the actual monitoring results, current and future conditions are simulated by ATMOS2 model for the country, and Airviro model for the BMR. Based on these outputs, the evaluation of acid deposition and ambient air pollution of the country and the prioritization of issues are the next steps for preparing the countermeasures.

7.1 Acid Deposition

In the year 2000, 4 monitoring sites data were available for the evaluation of acid deposition. The situation of acid deposition is summarized as follows.

- SO_4 and NH_4 ion concentrations of the urban site were higher than the rural and remote sites;
- On the other hand, the concentrations of Cl and Na ion in the remote site were not high;
- It may be regarded that the main source of SO_4 and NH_4 ions in the near urban area is human activity. And also it causes increased sulfur and nitrogen deposition;
- Concentrations of Cl ion and cation were almost the same value in all 4 monitoring sites. Generally speaking these ions are not influenced by human activity so much;
- The pH in urban site was lower than in the rural and remote sites, and
- The decrease of pH might be caused by human activities.

According to the monitoring result, it can be regarded that human activities caused additional sulfur and nitrogen deposition, and a decrease of pH of rain water.

In order to evaluate and review the possible technical options to mitigate substances that cause acid deposition, it is necessary to investigate and collect quantitative basis for the realization of acid deposition. Broad monitoring activities and variety of research, such as critical load, are prerequisites for quantitative approach. Currently, collected materials for acid deposition are fewer than materials for atmospheric pollution. It is untimely to prepare countermeasures quantitatively by the utilization of acid deposition data. Therefore, a major quantitative approach will be applied for the field of atmospheric pollution. In the following sections, ambient air pollution by substances that cause acid deposition, i.e. sulfur and nitrogen are evaluated. The critical load approach for acid deposition is described in supporting report as reference.

7.2 Ambient Air Pollution

7.2.1 Evaluation Method

In the first place, Thailand ambient air quality standard for SO_2 and NO_2 was adopted as the criterion. Moreover, on consideration that the ambient air quality shall be modified and improved in the light of scientific and technological progresses and changes in economic and social conditions of the country (NEQA, B.E. 2535), the WHO guidelines for SO_2 and NO_2 were taken into consideration.

The standard and guideline are prescribed for the respective averaging time. For SO_2, one hour , 24 hours and the yearly average are prescribed by Thai Government, and 10 minutes, 24 hours and the yearly average are prescribed by WHO. Because of the limitation by the monitoring interval of the ambient air quality, the 10 minute average by the WHO guideline cannot be evaluated. For NO_2, 1 hour value is prescribed by Thai Government, and 1 hour and yearly average are set by WHO. These values were utilized as criteria.

Pollution Control Department, Ministry of Natural Resources and Environment has been conducting ambient air quality monitoring in the country. The validated SO_2 and NO_2 data for the year 2000 by PCD monitoring network were objects for evaluation. Chapter 1 describes the results of evaluation.

After the validation of the model by adjusting trial simulation results for the year 2000 to the monitoring result for the year 2000, the simulation results of 2011 BAU case were utilized for the evaluation. For the country, the concentrations of SO2 of respective grids were simulated by ATMOS2 model. For the BMR, concentrations of SO_2 and NO_2 of the respective grids were simulated by Airviro Model. The grid size of the country was 0.1 degree by 0.1 degree for urban area and 1.0 degree by 1.0 degree for other area. That of the BMR was 500m by 500m. That was approximately 100km by 100km for whole Thailand when applied 1.0 degree by 1.0 degree. The simulation results of 2011 BAU cases were utilized for evaluation.

7.2.2 Evaluation of SO_2 Concentration

Based on the monitoring results (Chapter 1) and the simulation analysis (Chapter 6), atmospheric SO2 concentration is evaluated here.

7.2.2.1 Other than BMR

The evaluation results are summarized in Table. 7.2.2.1. According to the monitoring data, all stations satisfied Thailand ambient air quality standard and the WHO guideline. In 2011 BAU case, SO_2 was lower than the BMR in other than BMR area. Therefore, the area other than BMR are not current target for preparing countermeasures.

Table 7.2.2.1 Evaluation of SO_2 Concentration, Other than BMR

	Thailand Ambient Air Quality Standard			WHO Guideline	
	1 Hour Value	24 Hour Ave.	Yearly Ave.	24 Hour Ave.	Yearly Ave.
Value : ppb	300	120	40	44	18
Evaluation at Monitoring Stations, 2000	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
Evaluation of All Grids by ATMOS2, 2011 BAU	ATMOS2 is not adequate for the evaluation of attainment of air quality standard. (However, simulation results imply the yearly average of SO_2 is high in the BMR.)				
Evaluation by Airviro	Airviro is not a simulation model for the whole country.				

7.2.2.2 The BMR

Concerning the BMR, the evaluation results are listed in Table 7.2.2.2. Although Thai standard was satisfied by the monitoring and simulation results for the year 2000, it was not satisfied by 2011 BAU simulation case. The WHO guideline was not satisfied in the year 2000 by the monitoring and simulation results, and was not satisfied in the year 2011 by BAU simulation case. It is necessary to prepare countermeasures for SO_2.

Table 7.2.2.2 Evaluation of SO_2 Concentration, the BMR

	Thailand Ambient Air Quality Standard			WHO Guideline	
	1 Hour Value	24 Hour Ave.	Yearly Ave.	24 Hour Ave.	Yearly Ave.
Value : ppb	300	120	40	44	18
Evaluation at Monitoring Stations, 2000	Satisfied	Satisfied	Satisfied	6 out of 24 Stations did not Satisfy.	Satisfied
Evaluation by ATMOS2, 2011 BAU	ATMOS2 is not adequate for the evaluation of attainment of air quality standard. However, the simulation results imply the yearly average of SO_2 is high in the BMR.				
Evaluation by Airviro, 2000 Base Case	All grids satisfy the yearly average standard.			107 grids (0.4%) do not satisfy the yearly average guideline.	
Evaluation by Airviro, 2011 BAU case	3 grids do not satisfy the yearly average standard.			230 grids (0.9%) do not satisfy the yearly average guideline.	

Total grid: 26,320

7.2.3 Evaluation of NO_2 in the BMR

According to the monitoring result, Thailand ambient air quality standard was satisfied, and the respective the WHO guidelines were not satisfied in the year 2000. The simulation analysis showed that both Thailand standard and the WHO guideline were not satisfied in the year 2000 and 2011 by BAU Case. The result is summarized in Table 7.2.3.1. It is necessary to prepare mitigation measures.

Table 7.2.3.1 Evaluation of NO_2 Concentration, the BMR

	Thailand Ambient Air Quality Standard	WHO Guideline	
	1 Hour Value	1 Hour Ave.	Yearly Ave.
Value : ppb	170	98	20
Evaluation at Monitoring Stations, 2000	Satisfied	Not Satisfied	Not Satisfied
Evaluation of All Grids by ATMOS2, 2011 BAU	ATMOS2 is not a model for simulation of NO_2.		
Evaluation by Airviro, 2000 Base Case	91 grids (0.3%) show a higher simulation value than 40 ppb*.	2,452 grids (9.3%) do not satisfy the yearly average guideline.	
Evaluation by Airviro, 2011 BAU	60 grids (0.2%) show a higher simulation value than 40 ppb*.	2,127 grids (8.1%) do not satisfy the yearly average guideline.	

Total grid: 26,320

* For NO2, Thailand ambient air quality standard is 170 ppb, this value corresponds to the yearly average of 40ppb by correlation analysis of actual monitoring data.

7.3 Prioritization

The evaluation of acid deposition and ambient air pollution showed that the target area for mitigation in the whole of Thailand was the BMR. In the BMR, according to the monitoring and simulation results, SO_2 concentration satisfied Thai standard in 2000. However, concerning the WHO guideline, the monitoring results showed some stations did not satisfy the guideline, and the simulation analysis revealed that a considerable number of grids exceeded the guideline value, in the year 2000. The condition would deteriorate in the 2011 BAU Case. 3 grids would not satisfy Thai standard and more grids would not satisfy the WHO guideline.

Thai's ambient air quality standard for NO_2 was satisfied, however the WHO guideline was not satisfied in the year 2000. According to the simulation analysis, some grids did not satisfy Thai standard and the WHO guideline, in the year 2000. The condition would not be significantly improved in the year 2011 by simulation.

Consequently, it is necessary to introduce SO_2 and NO_2 mitigation measures for the BMR.

In order to prepare countermeasures for acid deposition and ambient air pollution, points of issue are the improvement of SO_2 concentration and NO_2 concentration in the BMR. Both are the issues for Bangkok and its vicinities as in Fig. 7.3.1.1. The concentration of human activities is accompanied with the considerable amount of pollutants discharge, sulfur oxides and nitrogen oxides. Thus air pollution is taking place. In the following chapter, reducing measures for sulfur oxides and nitrogen oxides are discussed.

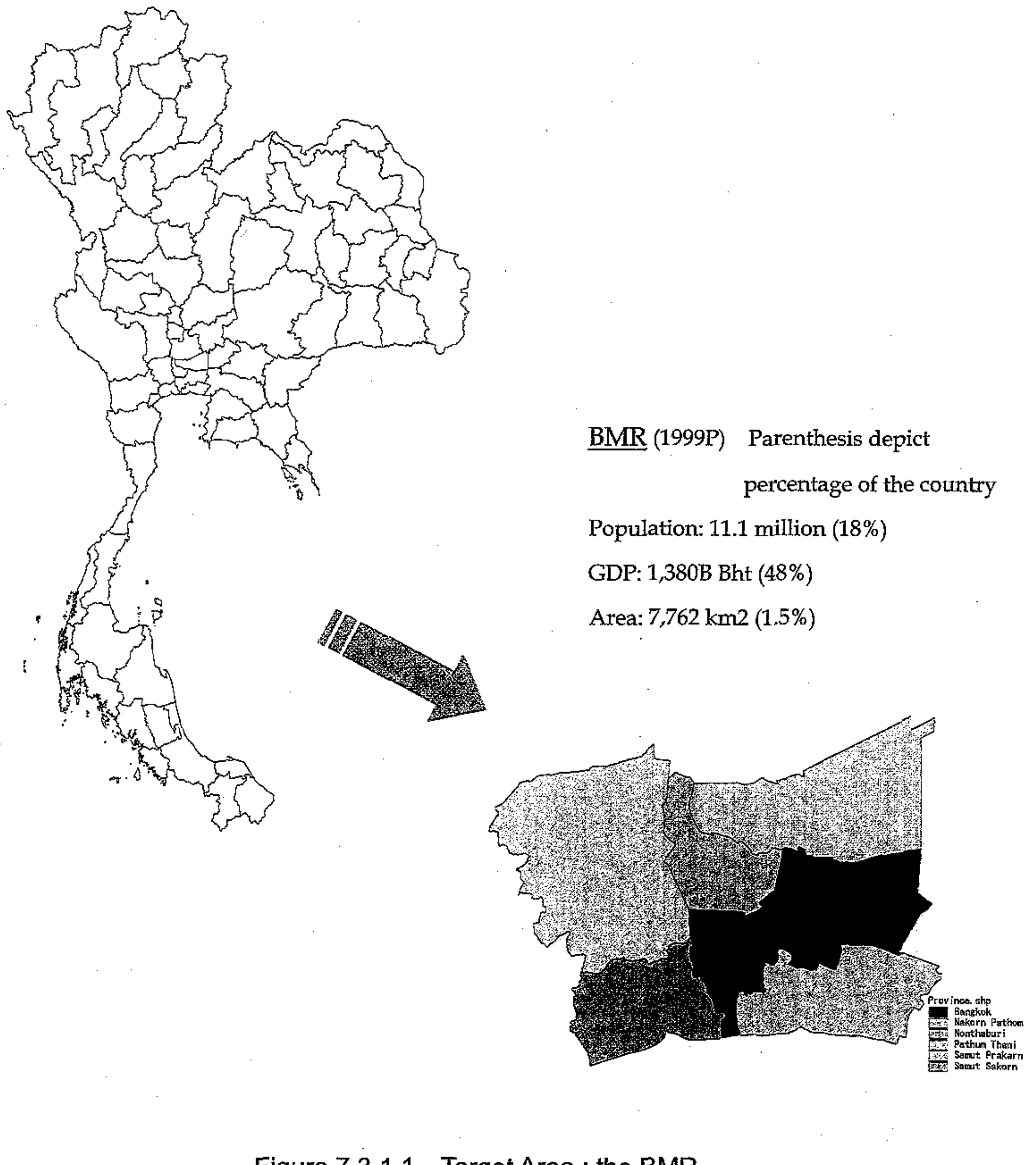

Figure 7.3.1.1 Target Area : the BMR

Currently, it is under discussion what is valid criterion for recognizing the effect of acid deposition in East Asia. For reference, if the idea of critical load (Supporting Report, Chapter 9) and 25% risk ratio value of critical load by BC/AL approach(RAINS-Asia Project) are adopted, the simulation by ATMOS2 shows following result (Supporting Report Chapter 6). In the year 2011 BAU case, the deposition values of almost all grids in the BMR exceed a critical load. It means deposition exceeds natural vulnerability. This is the case for Eastern and Central region also. The ratios of simulation value by critical load are approximately 5 in the BMR and 3 in Eastern and Central regions. In order to mitigate deposition, if the idea of critical load is applied, the possible scale of countermeasure will surpass the scale of SO2 and NO2 mitigation in the BMR. It is necessary to follow critical load approach.

Charpter 8

Countermeasures for SO2 in BMR

8. Countermeasures for SO_2 in BMR

8.1 Methodology

In the year 2000, as described in Chapter 1 and 7, all monitoring stations in BMR satisfied Thai ambient air quality standard for SO_2. Concerning WHO guideline, 6 out of the 24 stations in BMR did not satisfy the daily average and all stations satisfied the yearly average guideline.

As shown in Chapter 6, Airviro simulation showed that 107 grids did not satisfy WHO guideline in 2000. In the 2011 BAU case, 3 grids did not satisfy Thai standard, and 230 girds did not satisfy WHO guideline. Therefore, it is necessary to study countermeasure. In this Chapter, the countermeasure for mitigation of SO_2 is investigated following the methodology described in Fig. 8.1.1.1.

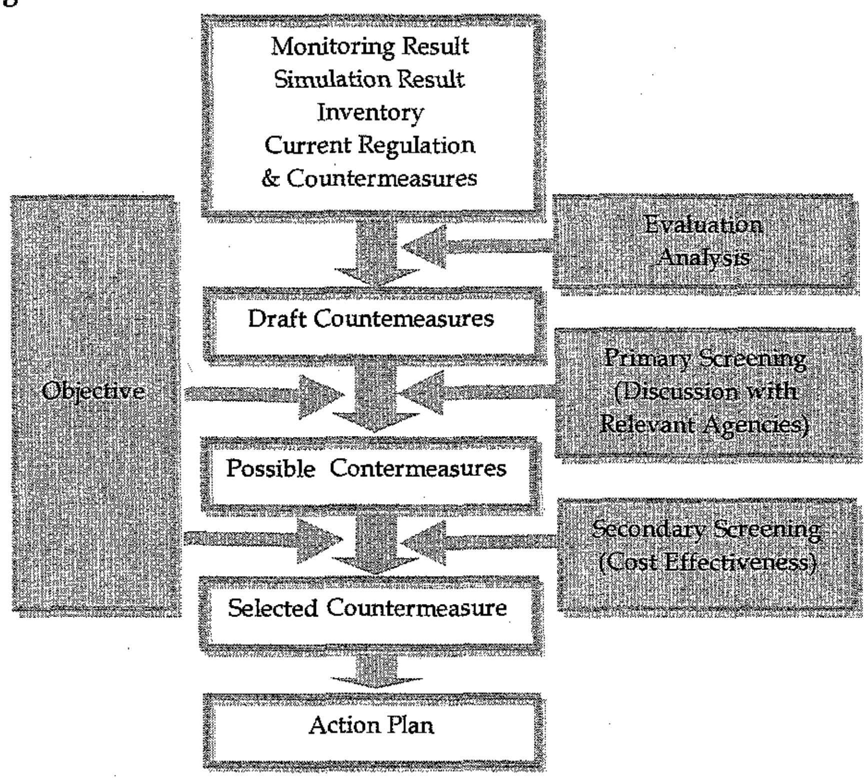

Figure 8.1.1.1 Methodology for Studying Countermeasure

First, the evaluation of monitoring and simulation result and analysis of inventory is necessary. Current regulation and countermeasures are also studied. After the evaluation and analysis, draft countermeasures are listed. The draft countermeasures are undergone primary screening that discusses whether they are applicable or not. The primary screening is carried out by discussion with relevant agencies. Possible Countermeasures by primary screening are examined in the view of cost effectiveness (Secondary Screening). An action plan for selected countermeasure is formulated.

8.2 Analysis of SOx Emission in BMR

The SOx emission amount of BMR by sector and fuel type are described in Chapter 5. As Fig. 8.2.1.1 shows, the share of manufacturing sector is 67% in the year 2000 and 92% in the year 2011 BAU Case. In the year 2011 BAU Case, because of fuel for power stations in Bangkok will be all converted to natural gas, the emission share of power station will decrease drastically. The share of manufacturing will increase significantly.

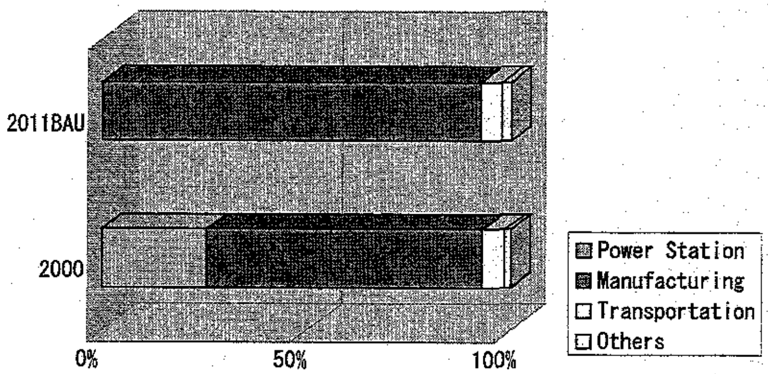

Figure 8.2.1.1 SOx Emission by Sector, BMR

As in Fig. 8.2.1.2, the share of fuel oil is 90% in the year 2000 and 88% in the year 2011 BAU Case. SOx from fuel oil is a target of reduction.

In order to mitigate SO_2 in BMR, the target of emission source is the fuel oil of the manufacturing sector.

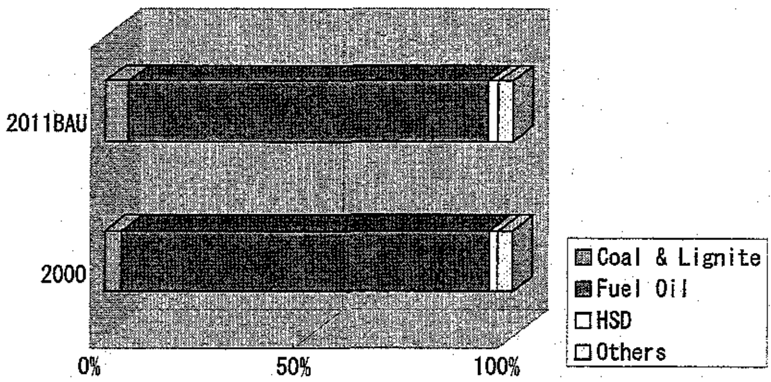

Figure 8.2.1.2 SOx Emission by Fuel Type, BMR

It is important to regard the difference of emission characteristics between the whole of Thailand and BMR. Concerning the whole of Thailand, SOx emission from coal and lignite is considerable. In the year 2000, the share of coal and lignite are 6.7% and 18.7%. And in the year 2011 BAU Case, the shares are 26.6% and 17.8 % respectively. The increase of coal in the year 2011 is significant. However in BMR, the share of coal and lignite is not considerable and that of fuel oil is dominant.

8.3 Current Mitigation Measures

Under current regulation for SOx, some areas in BMR show an unsatisfactory condition compared to ambient air quality standard. In order to investigate the mitigation measures of SOx pollution, the current regulation and current applied abatement measures are summarized.

8.3.1 Regulation

For sulfur oxides, the sulfur dioxide emission standard and the sulfur content specifications of oil products are the current major regulations. Table 8.3.1.1 shows the sulfur dioxides emission standard.

Table 8.3.1.1 SO_2 Emission Standard

Sources	Standard Value	Remark
H_2SO_4 production*	1,300mg/Nm3 or 500ppm O_2: 3.5%	
Heavy Oil as Fuel*	1,250ppm O_2: 3.5%	For Bangkok, Samutprakan, Nonthaburi, Pathumthani, Nakhonpathom, Samutsakhon, Chonburi, Rayong, Pechaburi, Songkhla, Prachuap Khiri Khun, Krabi, Phuket
New Power Plant*, ** >500MW Coal Oil Gas 300 - 500MW Coal Oil Gas <300MW Coal Oil Gas	320ppm 320ppm 20ppm 450ppm 450ppm 20ppm 640ppm 640ppm 20ppm O_2: 7%	Existing units of Bang Pakong, South Bangkok, North Bangkok, Surat Thani, Lan krabu, Nong Chok, Sai Noi, Wang Noi, Num Phong and Mae Moh power stations are enforced respective emission standard**.
Steel Industry** New & Existing	800ppm O_2: 7%	
Municipal Waste Incinerator** 1-50 ton/day >50 ton/day	30ppm 30ppm O_2: 7%	

* Ministry of Industry
**Ministry of Science, Technology and Environment

Factories or lines using coal and lignite as fuel other than power plants and steel industries are not regulated by the SO_2 emission standard. Besides factories and lines using heavy oil as fuel located in other provinces than Bangkok, Samutprakan, Nonthaburi, Pathumthani, Nakhonpathom, Samutsakhon, Chonburi, Rayong, Pechaburi, Songkhla, Prachuap Khiri Khun, Krabi, and Phuket are not regulated by the SO_2 emission standard.

Table 8.3.1.2 shows the specifications for sulfur in petroleum products.

Table 8.3.1.2 Specifications for Sulfur in Petroleum Products

Commodity	LPG	Gasoline	Kerosene	HSD	LSD
Sulfur Content	0.343g/m3	0.10 % wt	0.20 % wt	0.05 % wt	1.5 % wt
Commodity	Fuel Oil 1	Fuel Oil 2	Fuel Oil 3	Fuel Oil 4	Fuel Oil 5
Sulfur Content	2.0 % wt	2.0 % wt	2.0 % wt	2.0 % wt	0.5 % wt
Mandated Provinces	Bangkok, Samutprakan, Nonthaburi, Pathumthani, Nakhonpathom, Samutsakhon, Chonburi, Rayong, Pechaburi, Songkhla, Prachuapbkhirikhun, Krabi, Phuket				
Commodity	Fuel Oil 1	Fuel Oil 2	Fuel Oil 3	Fuel Oil 4	Fuel Oil 5
Sulfur Content	2.0 % wt	2.0 % wt	3.0 % wt*	3.0 % wt*	2.5 % wt
Mandated Provinces	Other Provinces				

Department of Commercial Registration
* From 2003, 2.0% wt

Concerning current administration for SOx mitigation, it is necessary to note the conditions of EIA approval. The EIA approval is undertaken by OEPP under environment law, i.e. NEQA 1992. Technical Reviewing Committee (TRC) under OEPP discusses the environmental mitigation plan of EIA. The condition recommended by TRC for the compliance of regulation and standard gives sometimes a base for implementing the abatement plant. In this context, some abatement measures such as FGD are installed.

8.3.2 Abatement Measures of Stationary Sources

In Table 8.3.2.1, typical situation of abatement measures for SOx are listed.

Table 8.3.2.1 Current Abatement measures for SOx

Measure	Current Situation
FGD	- Mae Moh power station installed FGD. - A pulp & paper factory (lignite firing) introduced FGD. - Fuel oil firing large power station installed FGD.
Low SOx Emission Plant	- Some boilers for power generation introduced Circulating Fluidized Bed Boiler.
Reduction of S Content in Fuel Oil	- Specifications of S contents in respective Fuel Oil type are introduced. - South Bangkok Power Station utilizes low sulfur Fuel Oil on necessary occasions.
Shift to Natural Gas	- Many power stations introduced natural gas. In 2000, 62.9% of electricity of the national grid was generated by natural gas.
Introduction of Low Sulfur Coal	- It is regarded that the sulfur content of imported coal is generally low. - Imported coal amount was 4.2Mton in 1990. A significant portion of them may be consumed by cement industry. Because cement kilns have a desulfurizing effect, S content of imported coal for the cement industry is not a subject for discussion.
Cleaner Production and Energy Saving	- The introduction of CP has started. - The introduction of Energy Saving are already implemented.

8.4 Countermeasures

In BMR, approximately 90% of SOx are discharged by stationary sources. Besides approximately 90% of SOx are emitted from fuel oil. In order to satisfy the SO_2 air quality standard and guideline, the reduction of SOx emission amount from stationary source is the measure of first priority. For the reduction of SOx emission, draft countermeasures are the reduction of sulfur content in fuel oil, the installation of flue gas desulfurization plant, the fuel shift from high sulfur fuel (fuel oil, coal and lignite) to natural gas, and the utilization of lower sulfur coal and lignite.

8.4.1 Reduction of Sulfur Content in Fuel Oil

Fuel oil is a major energy source in BMR. And fuel oil is a major source of SOx in BMR. The reduction of sulfur content in fuel oil is one of the draft countermeasures. Concerning oil products, in order to mitigate pollutant emission from mobile source, the sulfur content of gasoline and HSD are estimated to be reduced from 0.0382 w% and 0.0348 w% in the year 2000 to 0.015 w% and 0.03w% in the 2011 BAU case respectively. However, there is no plan for reduction of sulfur content in fuel oil in BMR.

1) <u>Background</u>

The combustion of fuel oil for heating sources result in SOx emission, and the SOx emission amount from fuel oil is huge. Fig. 8.4.1.1 shows the fuel oil consumption in BMR. In the year 2000, approximately 38% of fuel oil was consumed for electric power generation. On the contrary in the year 2011 BAU case, fuel oil consumption in power stations is zero. The reason for this is the fuel shift from fuel oil to natural gas by South and North Bangkok power stations. However, because of economic growth, the total consumption of fuel oil will not decrease significantly in the 2011 BAU case. The reduction of SO2 emission in BMR is a substantial measure for mitigating SO_2 concentration in BMR. The reduction of sulfur in fuel oil is a significant measure for the reduction of SOx from fuel oil.

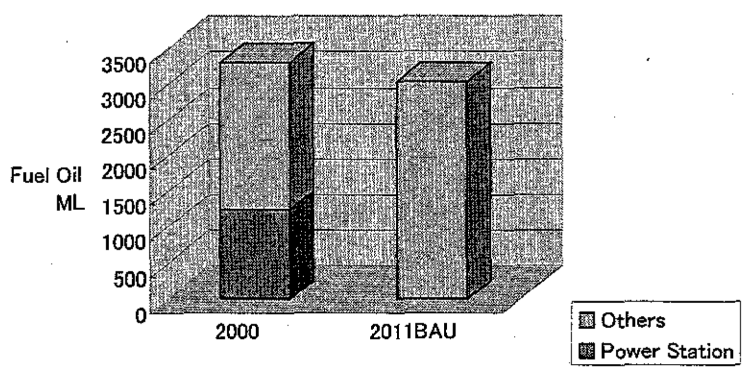

Figure 8.4.1.1 Cosumption of Fuel Oil in BMR

2) Concept of Countermeasure

In order to reduce the sulfur content in fuel oil, based on Enhancement and Conservation of National Environmental Quality Act (NEQA), B.E. 2535, it is necessary to introduce more stringent SO2 emission regulations and a corresponding sulfur concentration specification for fuel oil for BMR. Current sulfur specification for fuel oil 2 is 2.0% for BMR. In order to satisfy more stringent specification, refineries will modify their production configuration if necessary. Then refineries will supply low sulfur fuel oil to consumers in BMR.

3) Technological Aspect

In the year 2000, the majority of fuel oil type in Thailand was Fuel Oil 2, and the average sulfur content of fuel oil was 1.7%. The sulfur content of fuel oil depends on sulfur content of crude oil and the production configuration of the refinery. Major crude oil sources for Thailand are Asia and the Middle East. Generally oil fields in Asia produce low sulfur crude oil. Sometimes the sulfur content is approximately 0.1%. On the contrary, the majority of oil fields in the Middle East produce high sulfur oil, sometimes 2.0% S. It can be estimated that the average sulfur content of crude oil refined in Thailand is approximately 1% (Supporting Report Chapter 6).

The average crude oil sulfur content is regarded as 1.3% in Japan (Matsumura, Chemical Plant, Jul. 2000). After installation of direct or in-direct desulfurization process, sulfur content of fuel oil in Japan is approximately 1.1 to 1.2% (Petroleum Association of Japan, Supporting Report Chapter 6). According to experience, there is some scope for reduction of the sulfur content of fuel oil in Thailand by modification of the process. Based on the lower sulfur content of crude oil in Thailand, it will be possible to reduce from 1.7% to 1.2%.

8.4.2 Flue Gas Desulfurization

4) Background

Flue gas desulfurization is a direct SOx emission reduction method. The SOx in flue gas is removed by the abatement plant and removed sulfur is treated as by-products or waste. In Thailand, power stations and some industry have installed FGD. Mae Moh power station which utilizes lignite, installed wet type limestone-gypsum desulfurization plants (Kitcharoentanaruk and Eamyanyao, 2000).

5) Concept of Countermeasure

In order to enhance FGD, based on Enhancement and Conservation of National Environmental Quality Act (NEQA), B.E. 2535, it is necessary to introduce more stringent SO2 emission regulations for BMR. Currently, the emission standard for heavy oil as fuel is 1,250ppm (O2=3.5%) for BMR. On the contrary, the actual sulfur content in fuel oil in the year 2000 is 1.7%. Then SOx concentration in flue gas is approximately 1,000ppm (O_2=3.5%), and this value is below regulation. Therefore, currently almost all factories do not need the abatement measures for fuel oil consumption.

After the introduction of more stringent SO_2 emission regulations, factories that should comply with more stringent regulation will install a flue gas desulfurization plant (FGD). There will be some factories that will regard it to be better to shift to lower sulfur fuel such as natural gas than installation of FGD. Moreover, in some cases, factories will move to other provinces or stop to operation after the consideration of installation and operating cost of FGD.

6) Technological Aspect

In Thailand, a typical FGD plant is installed in Mae Moh power station which utilizes lignite, as in Table 8.4.2.1.

Table 8.4.2.1 FGD Plant of Mae Moh Power Station

Unit	4	5	6	7	8	9	10	11	12	13
Capacity MW	150	150	150	150	300	300	300	300	300	300
Starting Year of FGD	2000		1999		1997		1998		1995	

Note: No.1 to No.3 units were not operated in 2000.

Generally speaking, even if a production line is small, FGD can be installed technologically. In most cases, the feasibility of FGD depends on economic aspect. A paper and pulp factory installed a FGD plant. This plant treats waste gas of lignite firing. When deliberating EIA approval, Technical Reviewing Committee (TRC) under OEPP recommends sometimes the introduction of FGD or equivalent measures. In this context, FGD is technologically feasible in Thailand.

8.4.3 Fuel Shift to Natural Gas

In the year 2000, Thailand produced 713,130 MMscf natural gas, and the import amount was 78,041 MMscf. Out of the total primary energy supply, 25% was supplied by natural gas (DEDP, 2000). Natural gas is an important energy source, and domestic gas fields supply the majority of it.

1) Background

The fuel shift, from high sulfur content fuels such as fuel oil, coal and lignite to natural gas is a direct SOx emission reduction method. Although the sulfur content in natural gas is 9.5 ppm as H_2S, this amount is almost negligible compared to the sulfur content in other fuels. The current sulfur contents of fuel oil, coal, and lignite are 1.7%, 0.5%, and 2.0% respectively.

The share of natural gas in the power generation sector of Thailand is 62.9% (including hydroelectric power) in the year 2000 (DEDP, 2000). This amount is under dispute in view of national security. However, Thai Government encourages the fuel shift to natural gas in other sectors.

2) Concept of Countermeasure

Natural gas is an economically competitive fuel in Thailand. However the supplying area of natural gas is limited. The supply of natural gas is possible in areas around natural gas pipeline. Accordingly the ubiquitous regulation for the introduction of natural gas in BMR is not adequate for policy. The introduction of natural gas should be left to economic decisions of each company. Natural gas consumption in BMR is depicted in Fig. 8.4.3.1. The majority of natural gas is consumed in power station. In the year 2011 BAU case, all fuel of North and South Bangkok Power Stations will be natural gas.

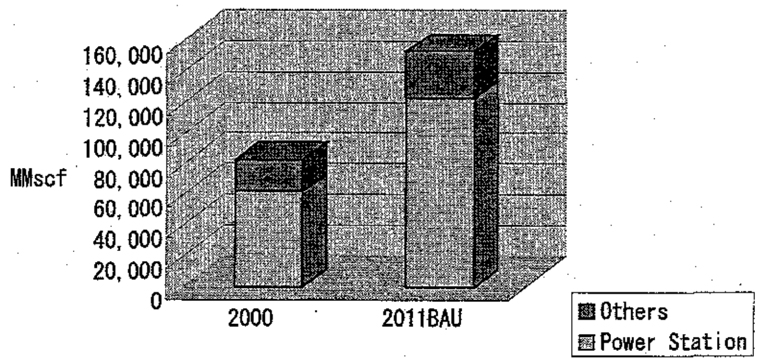

Figure 8.4.3.1 Natural Gas Consumption in BMR

Currently there is some scope of supplying capacity in BMR. There is a future pipeline plan for BMR. In order to supply gas to South and North Bangkok Power Stations, the approximate capacity of 146,000 MMscf pipeline will be finished in 2005. After the completion of this pipeline, the supplying capacity for the industrial sector will increase further.

In order to enhance the shift to natural gas and reduce SOx emission, it is necessary to convince consumers, i.e. factories, of its merit. The fuel shift to natural gas shows energy saving merits, and the price is competitive to other fuels. One of the possible methods for enhancement of shift to natural gas is to apply a Clean Development Mechanism (CDM). A shift to natural gas means reduction of CO_2 emission. However CDM is under consideration by Thai Government at present. In the mid 2003, the policy of Thai Government will be clearly built for CDM.

3) Technological Aspect

Many factories have already changed their energy source from fuel oil to natural gas. Currently in the manufacturing sector other than power stations, 56,805 MMscf of natural gas is consumed (DEDP, 2000). Needless to say, the shift to natural gas is technologically feasible, and may give some economical merit.

8.4.4 Utilization of Lower Sulfur Coal and Lignite

1) Background

The sulfur content of coal and lignite are regarded as 0.5% and 2.0% for industry. SOx emission from coal and lignite are generally large. It is necessary to study the possibility of reduction of sulfur content and the effect of reduction.

2) Concept of Countermeasure

Concerning power stations, there is an emission regulation for coal and lignite firing. Currently, other than power stations, coal and lignite firing plants are not regulated. In order to utilize lower sulfur coal and lignite, based on Enhancement and Conservation of National Environmental Quality Act (NEQA), B.E. 2535, it is necessary to introduce more stringent SO2 emission regulations for BMR.

4.2 million tons of coal were imported to Thailand in the year 2000 (DEDP, 2000). The sulfur content of coal was 0.5% in the year 2000. Other than Mae Moh power station, 4.3 million tons of lignite was produced and consumed in Thailand (DEDP, 2000). The sulfur content of lignite was 2.0% in the year 2000.

There are lower sulfur coal sources in the world, such as the coal mines in Kalimantan and Australia. However, sources that have less than 0.5% sulfur content coal are limited. At Mae Moh power station, lower sulfur lignite (sulfur content is less than 1.2%) is consumed in some cool seasons. In 1999, 1.6 million tons of low sulfur out of 14.0 million tons of lignite was consumed (Kitcharoentanaruk and Eamyanyao, 2000). Thus utilization of lower sulfur lignite is the limited case. And it is regarded that the domestic lignite source will be depleted in near future. It is not easy to expect a smooth supply of lower sulfur coal and lignite.

3) Technological Aspect

If lower sulfur coal and lignite are supplied steadily, there is no difficulty in the utilization of them. The probable reduction of sulfur content may be approximately 20%. However, the current SOx emission from coal and lignite in BMR is small. The share of them is only 4%. The introduction of lower sulfur coal and lignite may reduce approximately 0.8% (20% x 4%) of SOx in BMR. Therefore, this countermeasure cannot be expected as a sufficient one.

8.4.5 Cleaner Production and Energy Saving

Cleaner production (CP) and energy saving have environmental benefits. Therefore, the concept and effect should be reviewed. CP, or sometimes described as Cleaner Technology in Thailand, is promoted world-widely at present. The concept is an aggregation of relating movements having same direction that is beneficial for environment as well as profitable for enterprises. CP is effective for both SO_2 and NO_2 mitigation. In Thailand, a considerable number of agencies, such as PCD, DIW, MOAC and others tackles CP.

CP is a win-win measure. It is not only ecological but also profitable. As the introduction of CP into Small-and-Medium-sized-Economies (SMEs) is important and has started already, it is necessary to promote it nation-widely. Concerning the quantitative effect of CP, it cannot be estimated at present.

Energy saving, which is sometimes one of the major components of CP, is effective. The order of contribution to SO_2 reduction in Japan is reported as, from the highest, desulfurization, saving energy, shift to non-fossil fuel, and change to low sulfur fossil fuel (Li & Dai, 2000). The Japanese private industrial sector introduced widely the win-win mitigation measures, i.e. saving energy.

It is necessary to take into account that the energy consumption share of the industrial sector in Japan was dominant then. This is not the case in Thailand. The situation is shown in Fig. 8.4.5.1. However, energy saving is an effective measure.

With all efforts and an entire implementation of policy, the estimation of the maximum effect of energy saving is regarded as approximately 1% per annum (NEPO, 2002). Therefore, in this study, CP and energy saving are regarded not as specific countermeasures but as a general supposition for the estimation of energy consumption in the year 2011. The energy saving effect from 2000 to 2011 is regarded as 2%, considering the energy elasticity described in Chapter 2.

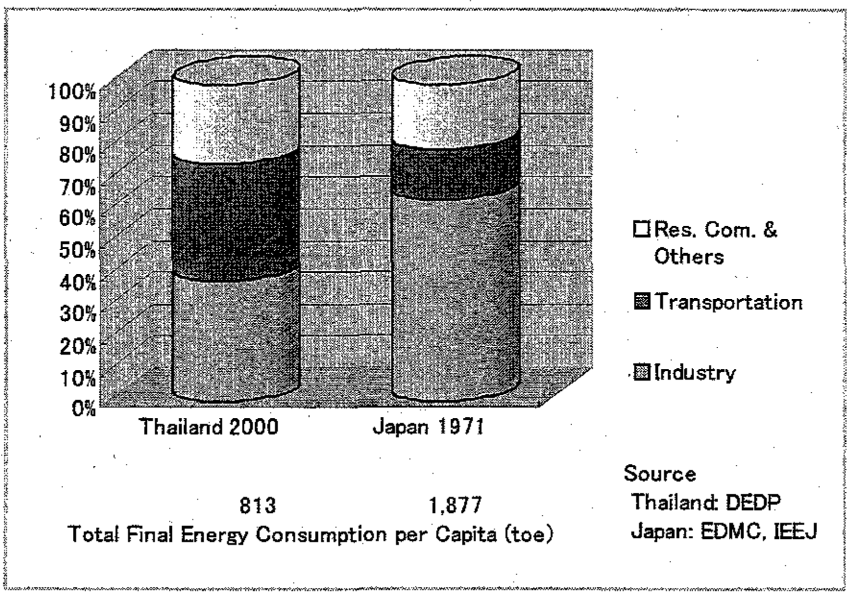

Figure 8.4.5.1 Share of Energy Consumption by Sector

8.5 Selection of Countermeasures

8.5.1 Objective of Countermeasures

It is necessary to formulate objectives of the countermeasure. According to the evaluation of current and 2011 BAU conditions, the objective of countermeasures are summarized as follows.

- Based on Airviro simulation, Thai ambient air quality standard of SO_2 (yearly average) will be kept in the year 2011.

- Based on Airviro simulation, the exceeding grids of WHO guideline of SO_2 (yearly average) will be reduced in the year 2011 than in the year 2000.

In order to study the countermeasures, it is necessary to have the idea of approximate SOx reduction amount. The reduction amount can be estimated by similar and precedent experiences. The sulfur content of fuel oil in Japan is approximately 1.2% (Petroleum Association of Japan, Supporting Report Chapter 6). This value suggests 30% reduction of S content in Fuel Oil, i.e. the reduction from sulfur content of 1.7% (Thailand, 2000) to 1.2% means 30% reduction approximately. In BMR, approximately 90% of SOx are emitted from fuel oil consumption. It is expected that a 30% reduction of S in fuel oil means the considerable reduction of SOx emission in BMR. Therefore, the equivalent SOx reduction to S reduction in Fuel Oil (1.7% to 1.2%) is adopted for a tentative reduction amount for the Study.

8.5.2 Primary Screening of Countermeasures

For primary screening of countermeasures, 3 aspects are reviewed. They are policy and administrative aspect, social aspect, and technological feasibility. Table 8.5.2.1 shows primary screening of respective measure.

According to the table, because of the small reduction effect of SOx, the utilization of lower sulfur coal and lignite cannot be regarded as an adequate countermeasure for whole BMR. However, if the mitigation of specified source emission is the target of mitigation in the future, the utilization of lower sulfur coal and lignite will be one of possible measure such as seasonal utilization of lower sulfur lignite.

Coal is abundant energy source in the world and has potential for wider utilization. And environmental problem of coal consumption can be mitigated by appropriate countermeasure. However, currently there is the difficulty for development new coal mine in Thailand due to public acceptance. It is not regarded as easy to supply lower sulfur coal and lignite steadily.

Table 8.5.2.1 Primary Screening

	Reduction of Sulfur Content in Fuel Oil	Flue Gas Desulfurization
Policy & Administrative Aspect	- Necessity of new or stringent regulations - Introduction of a supporting mechanism for refineries - Necessity of consistency with other regulations - Increase factor of administration costs	- Necessity of new or stringent regulations - Introduction of supporting mechanisms for FGD installation - Necessity of consistency with other regulations - Increase factor of administration costs
Social Aspect	- Pressure for financial status of refineries - Factor for fuel oil price increase - Logistics for supplying different quality fuel oil for BMR and other areas	- Cost increase factor for factories - Some factories without installation space will stop production or move to outside of BMR
Technological Feasibility	- Feasible - Considerable Reduction of SOx	- Feasible - Introduction of fuel shift by some factories - Considerable Reduction of SOx

	Fuel Shift to Natural Gas	Utilization of Lower Sulfur Coal & Lignite
Policy & Administrative Aspect	- Introduction of more beneficial incentives - Unnecessary of regulation - Accordance with current government policy to enhance introduction	- Necessity of new or stringent regulations - Necessity of consistency with other regulations - Increase factor of administration costs
Social Aspect	- Risk of gas leak from pipeline	- Difficulty of steady supply - Short life of many domestic coal mines - Difficulty of development of new coal mine, due to matter of social acceptance - Tendency of price increase
Technological Feasibility	- Feasible - Considerable reduction of SOx	- Feasible - Small reduction of SOx

8.5.3 Cost Estimation

Investment amounts and yearly costs of the three countermeasures, i.e. the reduction of sulfur content in fuel oil, the flue gas desulfurization and the fuel shift to natural gas are summarized in Table 8.5.3.1, and illustrated in Figure 8.5.3.1. The method of estimation is summarized in Chapter 6 of the Supporting Report. Because of the diversity of cost, estimation is based on a range of values. The SOx reduction amount of countermeasures is supposed to be 10,000 ton per annum in this estimation. This yearly cost includes repayments, depreciation, maintenance and energy saving merits.

The introduction of a fuel shift to natural gas leads to CO_2 reduction, and has the possibility of being treated as a CDM project. However, the CDM is under investigation by the Thai Government, the figures do not include the cost effect by applying the CDM.

According to the cost estimation, the fuel shift to natural gas is the most effective measure of the three.

Table 8.5.3.1 Cost Estimation

	Approx. Investment Amount (MBht)	Approx. Annual Cost (MBht/y)	Approx. Annual Cost (Bht/y/SO2 Reduction ton/y)
Reduction of S in Fuel Oil	600 to 2,500	200 to 1,000	20,000 to 100,000
Flue Gas Desulfurization	1,100 to 4,400	300 to 1,200	30,000 to 120,000
Fuel Shift to Natural Gas	900 to 3,500	90 to 400	9,000 to 40,000

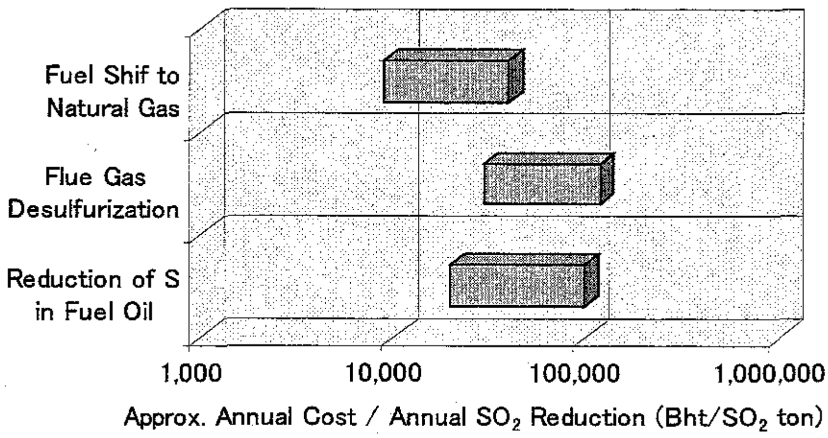

Figure 8.5.3.1 Cost Effectiveness

8.5.4 Secondary Screening of Countermeasure

Concerning the three measures, the environmental impact, financial issues and cost effectiveness are summarized in Table 8.5.4.1.

Table 8.5.4.1 Secondary Screening

	Reduction of S in Fuel Oil	Flue Gas Desulfurization	Fuel Shift to Natural Gas
Environmental Impact	- Reduction of SOx - Improvement of air quality - Necessity of adequate treatment of by-product or waste(removed sulfur)	- Reduction of SOx - Improvement of air quality - Necessity of adequate reatment of by-product or waste (removed SOx)	- Reduction of SOx - Reduction of smoke - Improvement of air quality - Land alteration by laying pipeline
Financial Issue	- Large investment amount - Large yearly cost - Necessity of Government support to refineries	- Large investment amount - Large yearly cost - Necessity of Government support to introduction	- Less investment amount comparing to other measures - Less yearly cost comparing to other measures - Necessity of incentive for introduction

Cost Effectiveness	- Less effective, comparing to shift to natural gas - Factor for cost increasing	- Less effective, comparing to shift to natural gas - Factor for cost increasing	- Most effective of three countermeasures - With energy saving merit

Screening is summarized in Fig. 8.5.4.1. The shift to natural gas is an advantageous countermeasure. For the control case, the shift to natural gas is selected.

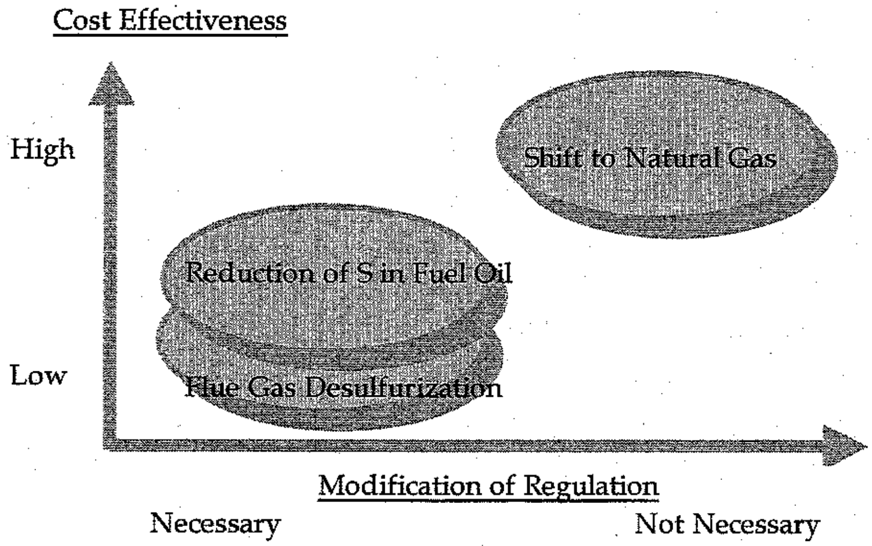

Figure 8.5.4.1 Screening of Countermeasure

When laying a natural gas main pipeline, according to the regulation, it is necessary to submit an EIA report. In the course of clearing the EIA procedure, appropriate environmental consideration will be applied and negative environmental impact will be minimized.

8.5.5 Effect of Countermeasure

The effect of the shift to natural gas is estimated by Airviro simulation with a SOx reduction of approximately 30%, as described in section 8.5.1. Simulation results for the 2000 Base Case and 2011 BAU Case for SO2 are described in Chapter 6. Concerning the shift to natural gas case (Control Case), the result of simulation is depicted in Fig. 8.5.5.1.

The grid numbers exceeding the standard and guideline are summarized in Table 8.5.5.1.

Table 8.5.5.1 Exceeding Grid Number

	Exceeding Thai Ambient Air Quality Standard	Exceeding WHO Guideline
	Yearly Average : 40ppb	Yearly Average : 18ppb
2000 Base Case	0	107
2011 BAU Case	3	230
2011 Control Case	1	35

According to the simulation result, Thai ambient air quality standard would not be kept by the Control Case. And the number of grid exceeding the WHO guideline would be reduced from 230 to 35. One of the objectives of the countermeasure that aims to satisfy Thai ambient air quality standard in the year 2011 might not be fully attained. Another objective that aims to reduce grids exceeding WHO guideline might be attained.

However, concerning Thai standard, the number of exceeding grid was only one. It is necessary to deliberate the nature of implication by simulation analysis. The major aim of Grid Module simulation was to estimate the general concentration pattern of the area. Moreover, the emission inventory of the stationary source of the 2011 BAU case was based on generalized economic growth pattern. Therefore the implication by Grid Module simulation was a generalized one. It was not adequate to discuss the condition of specific points. In order to estimate the ground surface concentration of specific grids in the future, it is necessary to apply other simulation models and detailed emission source conditions of target grids.

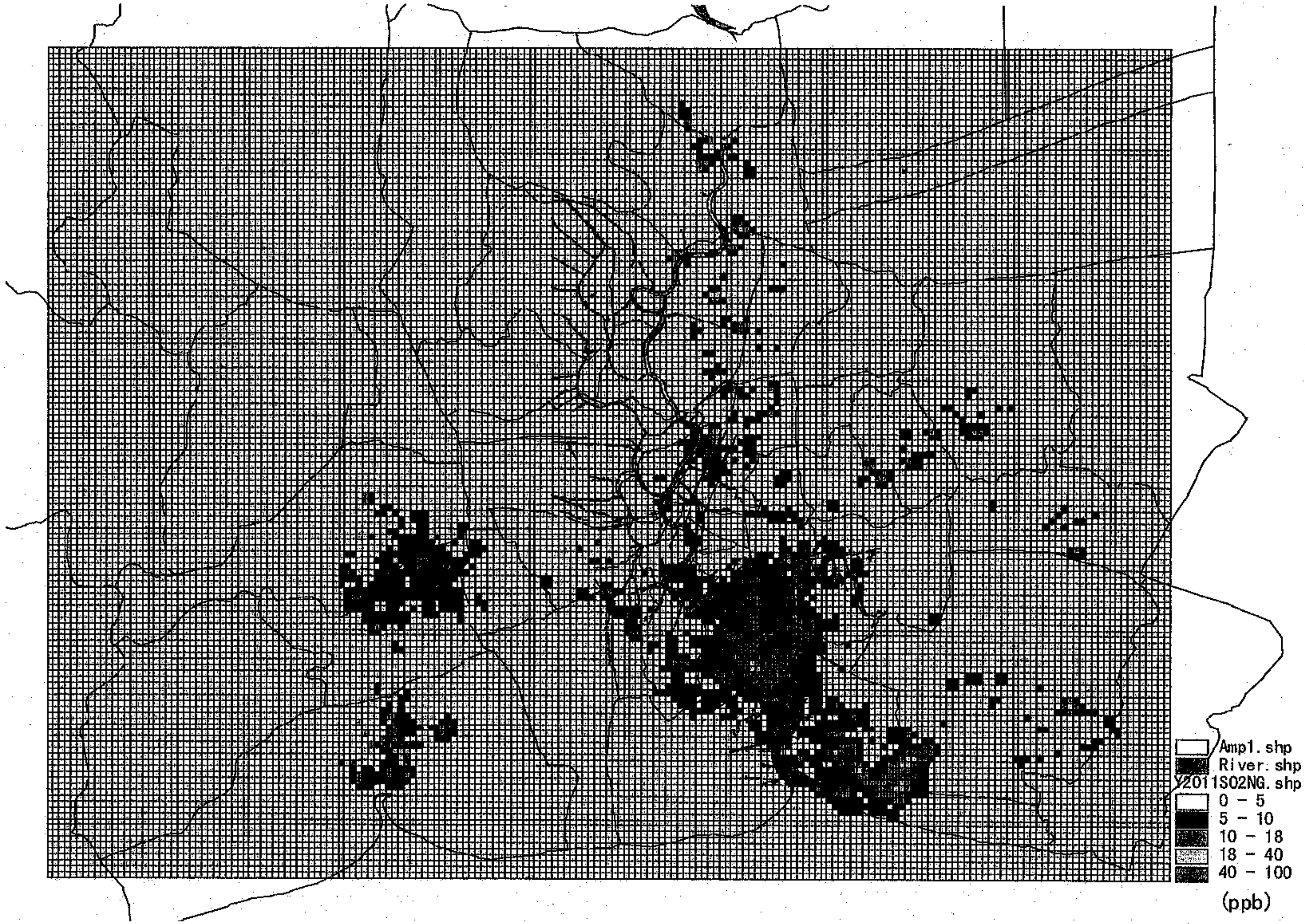

Figure 8.5.5.1 2011 Control Case : Shift to Natural Gas