EMISSION INVENTORY FOR AREA SOURCE: CASE STUDY IN MAJLIS BANDARAYA MELAKA BERSEJARAH (MBMB) REGION

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Abstract: The aim of this study is to investigate the air pollution emission and develop an emission inventory from area source in Majlis Bandaraya Melaka Bersejarah – Historical Melaka City Council (MBMB) region. The area source covers sources that are small in nature but releases air pollutants over a relatively limit area. In this case study, the area sources are residential cooking facilities, school canteens, petrol stations, car repair/garages, restaurants, open burning areas, and construction sites. The required data are obtained through questionnaire, interviews, and direct observation at sites in the region. Other related information was also obtained from validated and published data by government official publication such as Department of Statistics and Department of Environment (DoE). The calculation procedures and identification of emission factors in developing the emission inventory are based on CORINAIR Air Emission Guidebook 2013. The detailed emission data is then being plotted on the city map. The results show that fuel burning equipment from households and restaurants emitted higher air pollutants than other source categories. Overall, annual emission of Nitrogen Oxides (NO_x) was about 100.22 tons/year, Carbon Monoxide (CO) was 748.63 tons/year, Sulphur Oxides (SO_x) was 3.35 tons/year, Non-Methane Volatile Organic Compounds (NMVOC) was 197.10 tons/year and Particulate Matters (PM_{10}) was 100.49 tons/year. The results from the emission inventory identified key sources of air pollution for the city will be the basis for the future Melaka City Clean Air Plan (CAP) development.

***Keyword**: Emission Inventory; Area Sources; Emission Factor*

INTRODUCTION

Emission inventories are the foundation of air quality management. An emission inventory is a comprehensive database of geographically referenced datasets of atmospheric emission sources and contains information about the location of sources, types of sources and processes with emissions of air pollutants**,** rates of emissions and quantity of specific pollutants emitted into the air. Identifying the sources of major impact on air quality is a prerequisite for the development of effective measures to reduce ambient air pollution, for instance in the framework of a clean air and action plan. Incomplete or wrong emission inventories may therefore cause wrong decisions, which may result in high costs. Obtaining accurate and complete emission inventories thus is extremely important and cost-effective.

Majlis Bandaraya Melaka Bersejarah (MBMB) is the first city nominated to begin the development of emission inventory in Malaysia. MBMB sits in Central Melaka (Melaka Tengah), covers an area of 273 km^2 with 471 thousand inhabitants. As is the case for many other developing cities in ASEAN country, MBMB has been dealing with environmental problems arising from urbanization and economic growth. Air pollutants from various sources within the city contribute to environmental degradation and at some point, could affect the health of its inhabitants.

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The source of air pollutants emission comes from different source categories. One of the three categories of sources namely area source was considered for this study. In addition, there are six pollutants namely particulate matter (PM_{10}), nitrogen oxides (NO_X), sulphur dioxides (SO_2), carbon monoxide (CO) and volatile organic compounds (VOC) are included in the inventory.

Area sources are any sources that are small in nature but releases air pollutants over a relatively limit area and they are sometimes difficult to classify as point sources. Several emission inventory reports considered as the sources that may not be clearly distinguish from stack and sometimes agglomerated from small sources as one big source. Area sources are defined as sources that are too small and/or too numerous to be considered as point sources (United State Environmental Protection Agency, 2001). In aggregate, these sources may contribute a significant proportion of total air shed emissions. The area sources include a wide range of sources such as residential cooking facilities, petrol stations, and construction and demolition sites and so on.

METHODOLOGY

The method of calculation in this study was based on CORINAIR 2013 (European Environment Agency, 2013), which divided into three phases, namely as data gathering, emission calculation, data compilation and data quality control as well as quality assurance.

Data Gathering

The development of emission inventory in MBMB used "semi bottom-up" approach where the data are collected from individual sources and not derived from a national or regional estimate. We call "semi" because not all necessary data to calculate the pollutant are available. However, this approach is time consuming and require a large amount of data.

Data gathering involved the steps shown in Figure 1. Most of the primary data was provided by MBMB and Department of Environment (DoE). If some data needed from other institutions or agencies than MBMB and DoE, the request must come through the formal agencies. UTeM will pass the request through MBMB or DoE. Secondary data usually obtain by direct observation and survey.

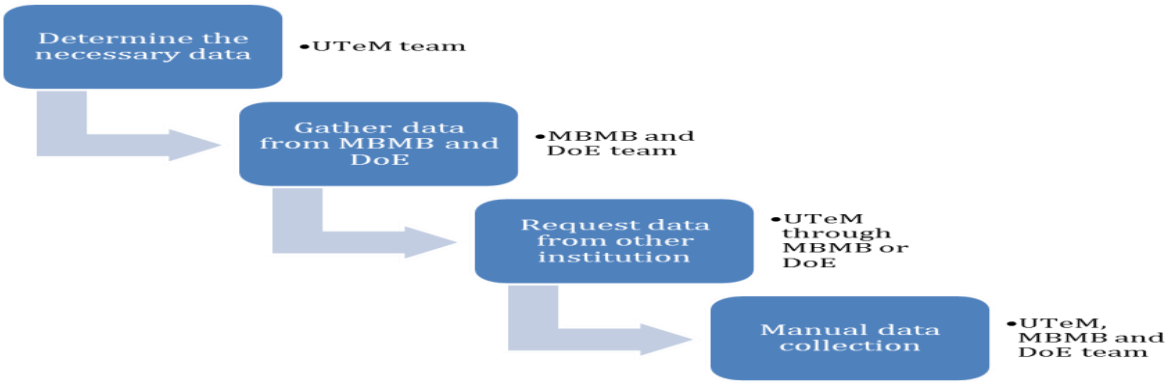

Figure 1: Step in Data Gathering

Emission Calculation

The general equation is used for emissions estimation based on CORINAIR 2013.

$$ER = AR \times EF \quad (1)$$

where,

ER = Emissions rate
AR = Activity data/rate
EF = Emission factor

Quality Assurance/Quality Control

Internal quality control steps should be briefly outlined in the inventory preparation plan and should include the following items:

(a) Checking emission calculations for errors
(b) Checking emission factors to ensure appropriateness of the factors used
(c) Documenting all the assumptions made during emission calculations
(d) Comparing the magnitude of calculated emissions with other source categories
(e) Comparing the magnitude of calculated emissions with existing/previous study

RESULT AND DISCUSSION

The result and discussion from this research focussed on the emission rate of air pollutants, the type of area sources and area covered under the MBMB region.

Emission Rate of Air Pollutants Entity

The discussion of the result begins with showing the total emission rate from area source in MBMB region as shown in Table 1.

Table 1*:* Emission Rate from Area Sources in MBMB Region

Emission Rate (ton/year)				
NO_x	**SO_2**	**NMVOC**	**CO**	**PM_{10}**
100.22	3.35	197.10	748.63	100.49

The study indicates that CO emission is the largest pollutants in MBMB region emit from area sources followed by the NMVOC, PM_{10}, and NO_x. On the other hand, the smallest amount of emission rate is from the SO_2. Next section, will further explained the significant finding from this study.

Emission Rate from Type of Area Sources

There are eight types of area sources covers in this study which are emission from household/residential fuel burning, restaurants, school canteen, petrol stations, car repair and garage, construction sites and open burning locations.

1. **Household/Residential Fuel Burning**

Household/residential fuel burning is undertaken for cooking and hot water heating. Residential and household fuel is mainly liquefied petroleum gas (LPG). It was found that LPG dominates the fuel share used in the MBMB households. Emissions depend not only on the amount and type of the fuel burnt but also on the temperature and efficiency of combustion.

The required data are obtained by using questionnaires (randomly sampling) and interviews to estimate the emission rates. In this inventory, questionnaires were distributed to the residents, restaurants, and so on. The average of fuel consumption in each sub-location was calculated from the amount of fuel consumption divided by the number of dwellings. The assumption that there was no difference in the fuel consumption rate per capita among different residential buildings.

The emission rates are estimated from the number of households and the fuel consumption rate per household. The emission factors for charcoal and LPG combustion were based on CORINAIR 2013 uncontrolled residential fuel burning. The emission factors were selected based on the fuel type as shown in Table 2.

Table 2: Emission Factors for Household/Residential Energy Usage.

Categories	**Unit**	**Emission Factor (g/GJ)**				
		NOx	**CO**	**SO_2**	**NMVOC**	**PM_{10}**
LPG	g/GJ	60	30	0.3	2	2.2

Our findings reveal that the total emission rates for household/residential in MBMB region are CO (8.4962 tons/year); PM_{10} (0.6231 tons/year); NMVOC (0.5664 tons/year); NO_x (16.9925 tons/year) and SO_2 (0.085 tons/year).

2. Restaurants

Similar with household, fuel burning is undertaken for cooking and hot water heating. Restaurant fuel is mainly liquefied petroleum gas (LPG) and charcoal. Figure 6 and 7 show the common cooking utilities available in the restaurants. Interviews were conducted with the restaurants' owners and questionnaires were distributed and to obtain the fuel consumption data. From 48 restaurants, the total fuel consumption is 725.76 tons/year of LPG and 172.8 tons/year of charcoal.

Table 3: Total emissions from the restaurants of MBMB.

Fuel	**Emission rate (ton/year)**				
	NO_x	**CO**	**SO_2**	**NMVOC**	**PM_{10}**
LPG	72.63	36.31	0.61	24.21	0.61
Charcoal	9.89	703.39	2.65	122.76	92.24
TOTAL	82.52	739.71	3.26	146.97	92.84

3. School Canteen

School canteens are also included in this study due to the cooking activities involved. Similar emission factors for households and restaurants have been used in order to estimate the emissions from the school canteens. The estimated emissions for the school canteens are shown in Table 4.

Table 4*:* Total emissions from the school canteen of MBMB

Emissions (ton/year)				
NO_x	**CO**	**SO_2**	**NMVOC**	**PM_{10}**
0.6951	0.1790	0.0018	0.0118	0.0128

4. Petrol Stations

Petrol stations was considered as an area source in this study since they did not have distinct emission point but their activities contributed to a specific air pollutant - NMVOC. Their activities mainly involved fuel unloading, vehicle refuelling and vehicle services. Data on the number of petrol stations were obtained from the municipality registry.

Questionnaire was used as a tool for data collection along with direct observation on vehicle refuelling. The data available from petrol stations included fuel type, associated activities, and amount of fuel sale. Based on the available data and estimation, the total sale for gasoline was about 612.7 million litters while diesel was about 338.21 million litters. The emission factor was derived from CORRINAIR 2013, section 1.B.2.a.v for gasoline (Table 5). In this case, the estimation assumed that there is no spill from unloading to underground storage tank and no spill from overflow during the service to motor vehicles. These assumptions were made as there is no available data to justify these issues and automatic shut-off mechanism do exist.

Table 5: Emission factors (EF) for NMVOC from petrol station

Technologies/Practices	**EF of NMVOC (g/m^3 throughput/kPa TVP)**
Storage tank filling	24
Automobile refuelling with no emission	37
Total	61

The annual average of NMVOC emissions from petrol stations was related to the amount of gasoline sale. Overall, the petrol stations in MBMB emitted about 37.38 tons/year of NMVOC.

5. Car Repair & Garage

Car repair and workshop falls in the area source category due to the usage of several kinds of paints, including primers, topcoats, and hardeners to repair and refinish damaged motor vehicles, with the aim to protect the substrates (usually metal) from corrosion, abrasion, and decay. The paint and solvent components are composed of the mixtures of VOCs which are emitted during the refinishing, drying, curing and hardening phases. The solvent acts as a carrier for the resins and pigments and evaporates as the paint film formed during the drying process. All surface coatings used in the industry are assumed to evaporate to the atmosphere. Oil-based paints consist of 30% to 70% VOCs by weight, while water-based paints consist of about 6% VOCs. Thinners, used for cleaning, consist of 100% VOCs.

The local paint consumption data were obtained from both industrial information research and from direct interviews. Data on name, location, number of serviced cars, quantity of solvent used and details of drying room were obtained. That information would assist in estimating paints and solvents applied. The total amount of paints used for car repairing in MBMB are 14076 L/year.

The emission factors for NMVOC from car repair/garage are given in Table 6. The total emissions of NMVOC per year were calculated are 12.16 ton/year based on the density of paint is taken as 1.2 kg/L.

Table 6: Emission factors for NMVOC from garages

Car Repair and garages	**NMVOC**	**Conditions**	**Remark**
Industrial coating application	720 g/kg	Vehicle refinishing	Tier 2

6. Construction Sites

Pollutants from construction sites are typically from construction processes and internal combustion engines. However, there were no data on the number, type of machineries and vehicles used for

construction. So, the emissions from machineries were not included in this inventory. The main pollutant that emitted from the construction activities is particulate matters (PM).

Property owners within MBMB region are required to submit the details of construction project including type of building, number of floor, working area, usable area, etc. to get permissions from relevant authority before construction. Thus, the activity data of construction sites obtained from MBMB including name, location, constructed area, and structure of building were fairly useful and reliable. The inventory includes the construction building with less and more than 3 stories building. The construction periods were assumed to be 0.67 and 1 year for buildings with 3 stories and those with more than 3 stories respectively as shown in Table 7. These data were derived from 38 cases of construction permits in 2011.

Table 7: Activity Data of Construction Sites.

Size of building	**Total Area (m^2/year)**	**Construction Period (year)**	**Activity Rate (m^2)**
Less than 3 stories	120,949	0.67	81035.99
More than 3 stories	5221.24	1	5221.21

The emission factors for construction activities were taken from Table 3.1 Section 2.A.7.b of CORRINAI 2013 as shown in Table 8.

Table 8: Emission factors for construction sites

Category	**Building Area Emission Factor (kg/m^2/year)**		
	TSP	**PM_{10}**	**$PM_{2.5}$**
Construction	0.162	0.0812	0.00812

The estimated emissions of TSP and PM_{10}, from construction buildings in MBMB region are estimated to account for about 13.97 tons/year and 7.00 tons/year respectively while PM2.5 are 0.7 tons/year.

7. Open Burning

Open burning is considered as an area source in the emission inventory. The area considered for the emission inventory in MBMB region includes housing, industry, small agriculture, and thicket which has potential to emit pollution from open burning activities in respective area.

The data on open burning activities recorded from public complaints received by Department of Environment. Next, investigation was conducted and relevant data was recorded by them. The emission factors were derived from CORRINAIR 2013 and (Gadde, et al., 2009) show in Table 9. The assumption was that the whole complaint area was burned.

Table 9: Emission Factor for Open Burning

Emission Factor (kg/Mg/year)				
PM_{10}	**CO**	**NO_X**	**SO_2**	**NMVOC**
4.51	55.83	3.18	0.11	1.23

Table 10: Pollutant Emitted in MBMB Region from Open Burning Activities.

Pollutant Emitted (ton/year)				
PM_{10}	**CO**	**NO_X**	**SO_2**	**NMVOC**
0.020	0.244	0.014	0.000	0.005

Distribution of Pollutants and Thematic Map

Figure 2 shows the distribution of pollutants in MBMB Region. The study indicates that for the NO_X, the highest distribution of pollutants is from the restaurant that using LPG while for the SO_2, the highest distribution of pollutants is from restaurant that using charcoal.

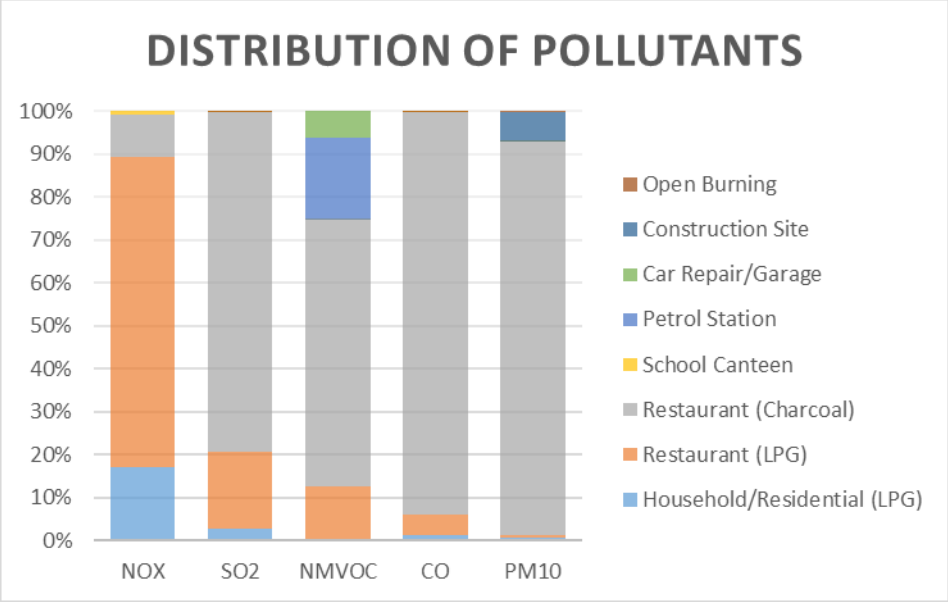

Figure 2: Distribution of Pollutants

Thematic map was used in this study to identify the hotspot in MBMB region. Based on Figure 3 to Figure 7, the finding provides evidence that the most concentrated area source in MBMB region is in the city centre and nearby area.

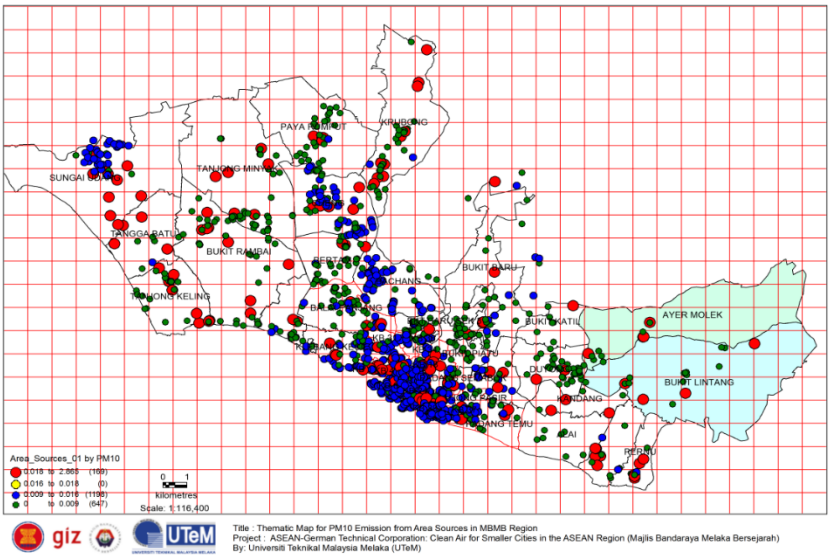

Figure 3: PM_{10} Emission from Area Source in MBMB Region

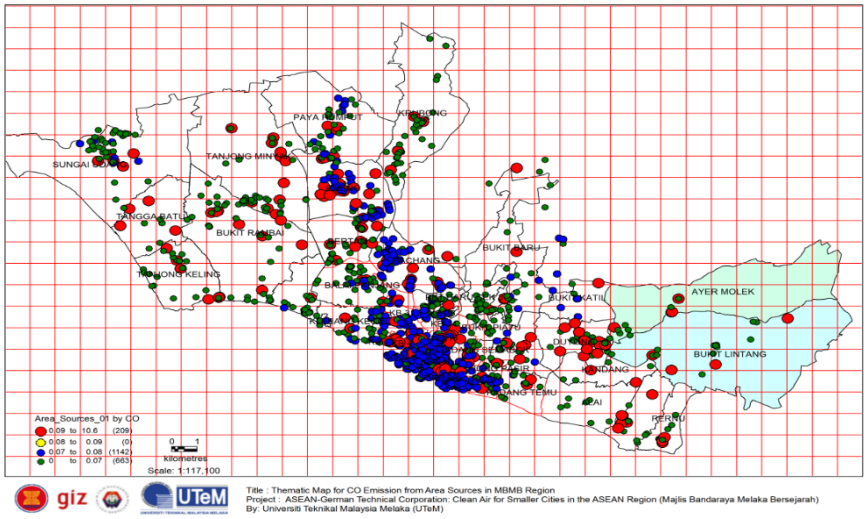

Figure 4: CO Emission from Area Source in MBMB Region

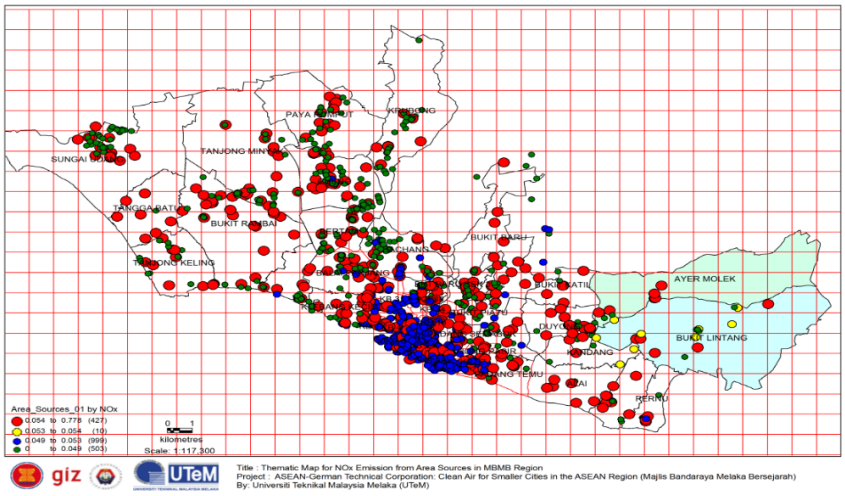

Figure 5: NO_x Emission from Area Source in MBMB Region

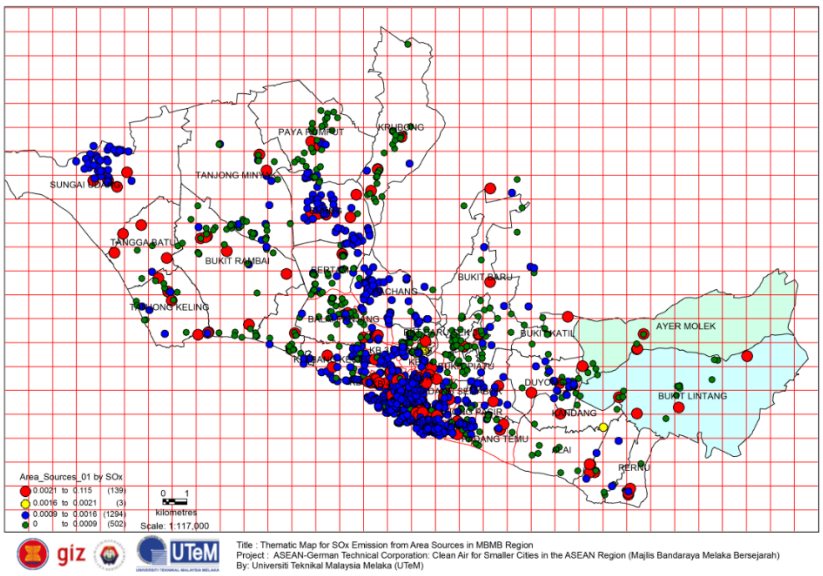

Figure 6: SO_x Emission from Area Source in MBMB Region

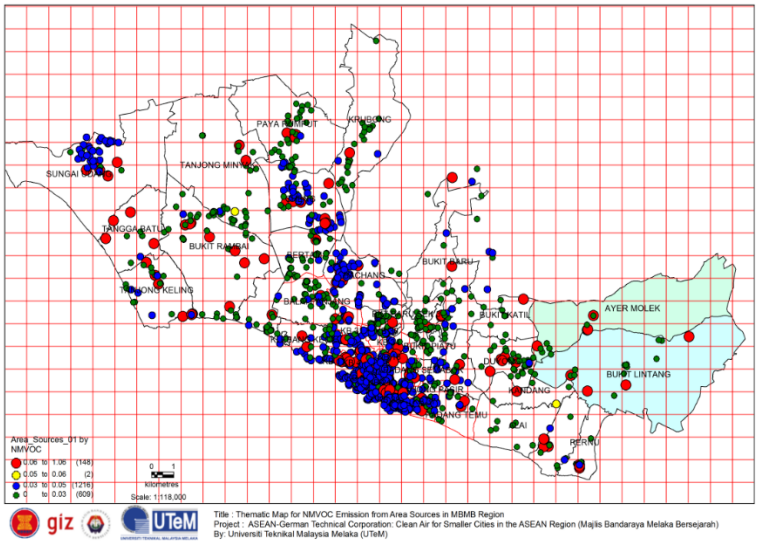

Figure 7: NMVOC Emission from Area Source in MBMB Region

CONCLUSION

In this investigation, the aim was to establish emission inventory database covering the MBMB region. The study has found that generally the most concentration air pollutants in the region is CO followed by NMVOC, PM_{10}, NO_x and SO_2. In addition, the most concentrated area is in the city centre and its nearby location. Findings from this project provides important information to develop green action plan for the MBMB local authority.

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REFERENCES

European Environment Agency. (2013). *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013.* Retrieved 10 19, 2016, from http://www.eea.europa.eu/publications/emep-eea-guidebook-2013

Gadde, B., Bonnet, S., Menke, C., & Garivait, S. (2009). Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. *Environmental Pollution, 157*(5), 1554-1558.

United State Environmental Protection Agency. (2001). *Introduction to Stationary Point Source Emission Inventory Development Volume 2.* Retrieved 10 18, 2016, from https://nepis.epa.gov/Exe/ZyNET.exe/2000CVV8.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=