Planning of Conventional Air Emission Reduction Strategy from the Transportation, Domestic, and Solid Waste Sector in Salatiga City

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Regional Case Study

Planning of Conventional Air Emission Reduction Strategy from the Transportation, Domestic, and Solid Waste Sector in Salatiga City

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Abstract
In 2020 Salatiga City has a population of 192,322 people with a population growth rate of 1.18%. The increase in population causes an increase in consumption needs, waste generation, and the number of vehicles due to increased population mobility. The purpose of this plan is to take an inventory of conventional air emissions in the transportation, domestic, and waste sectors and to plan strategies to reduce conventional air emissions in Salatiga City. The transportation sector emissions inventory is calculated using the Tier 2 method, while the domestic and solid waste sectors are calculated by multiplying activity data by emission factors. In the calculation of the capacity, the box model method is used and the SWOT analysis is used to determine the emission control strategy. The results of the inventory of conventional air emissions in the transportation sector for SOx are 121.06 tons/year, NOx is 2,615.51 tons/year, CO is 18,040.89 tons/year, and PM10 is 299.66 tons/year. Meanwhile for the domestic sector, SOx is 0 kg/year, NOx is 14,755.53 kg/year, CO is 4,070.86 kg/year, and PM10 is 190,326 kg/year. Then from the solid waste sector, SOx emissions were 3,653,071.85 g/year, NOx was 21,918,429.85 g/year, CO was 306,858.017.94 g/year, and PM10 was 219,184,298.53 g/year. . The results of the capacity calculation show that the City of Salatiga can still accommodate conventional air emissions for SOx, NOx, CO, and PM10. However, a reduction strategy is still needed to control air pollution. The strategic plan used is an increase in green open space by 20%, the development of an Intelligent Transportation System, emission testing of private vehicles, the substitution of LPG with biogas from organic waste and livestock manure, as well as community development for waste reduction and optimization of waste facilities.

Keywords: Conventional air emission; reduction strategy; transportation; domestic; solid waste

1. Introduction

The problem of air pollution has now become a worldwide concern because it is a major threat to climate change and health. Based on data from the World Health Organization (WHO), 91% of places in the world have air quality that exceeds the limits set by WHO. Air pollution occurs along with the increase in the human population. Indonesia has population growth in 2020 of 1.25%. Then for the City of Salatiga itself, it has a population growth rate of 1.18% for 2020. Viewed from a positive perspective, this increase in population can increase development in other sectors such as the transportation and industrial sectors (Abidin et al, 2019). However, the increase in population also results in an increase in human activity which affects the increase in the number of vehicles, consumption needs, and the generation of waste generated.

Salatiga is one of the cities in Central Java Province and is included in the national strategic area of Kedungsepur. The strategic location results in heavy traffic due to vehicles from other cities passing by so it has the potential to increase air pollution. Based on the Regional Long-Term Development Plan (RPJPD) of Salatiga City for 2005 – 2025, waste processing in Salatiga City is carried out in two ways, namely traditionally and through institutions. Traditionally it is done by hoarding and burning, while the system means through institutions. The existence of limited facilities and infrastructure makes transportation not optimal, plus the waste generation in Salatiga City has increased. Then based to the Central Bureau of Statistics of Salatiga City in 2021, per capita expenditure also increased and was dominated by commodities from households such as fuel.

The existence of these factors causes an increase in emissions which results in a decrease in air quality and pollution. In Aritenang (2019) it is stated that 70% of air pollution sources come from the transportation sector. This is supported by Marlena's research (2018), it is known that the activities of the transportation and domestic sectors in Semarang City can contribute to CO, HC, NOx, PM_{10}, and SOx emissions. Meanwhile, data from the Environment explains that the activity of burning waste in Jakarta can contribute to 41% of Jakarta's dust sources. Then in Bestar's research (2012), it was explained that the existence of open burning activities in Depok City could contribute to SOx emissions of 3,613 tons/year and NOx of 21,679 tons/year.

The negative influence of existing air pollution has an impact on the lives of living things and the environment. Therefore, it is necessary to have an inventory of emissions and management efforts. The inventory serves as a data provider for determining the status of ambient air because it can show potential emissions in detail. The results of a complete study on the emission inventory can be used as a management plan in the form of an air reduction strategy in the transportation, domestic, and waste sectors. The results of this strategy can be used as a basis for controlling and managing air quality.

2. Method

2.1. Emissions Inventory in the Transportation Sector

Types of vehicles selected for the transportation sector emissions inventory are motorcycles, cars, buses, and trucks. The transportation sector emission load calculation uses the Tier 2 method with an emission factor based on VKT *(vehicle kilometer traveled)*. The emission factor used refers to the Regulation of the State Minister of the Environment Number 12 of 2010 concerning the Implementation of Air Pollution Control in the Regions.

Table 1. Motor vehicle emissions factors

Category	**Emission Factors (g/km)**			
	CO	NOx	PM_{10}	SO_2
Motorcycles	14	0.29	0.24	0.008
Cars	32.4	2.3	0.12	0.11
Buses	11	11.9	1.4	0.93
Trucks	8.4	17.7	1.4	0.82
Pickups	31.8	2	0.026	0.13

Category	Emission Factors (g/km)			
	CO	NOx	PM10	SO2
Minibusses	24	1.55	0.029	0.14

Source: Regulations Minister of Environment Number 12 of 2010

a. Line Source VKT

VKT calculation of line source VKT is used to calculate mobile source emissions on main road sections.

$$\text{Line source VKT} = \sum_{i=1}^{n} Q_{ji} \times l_i$$

$$\text{Line source emission} = \text{VKT} \times \text{EF}$$

Q_{ji} = volume of j vehicle category on i road segment (vehicles/year)
l_i = length of i road segment (km)
EF = emission factor

b. Total Source VKT

$$\text{Total source VKT} = \text{VKT}_{odo} \times N$$

$$\text{Total source emission} = \text{VKT} \times \text{EF}$$

VKT_{odo} = vehicles VKT based on odometer survey (km/year)
N = number of vehicles category
EF = emission factor

c. Area Source VKT

Calculation of area source VKT is used to calculate emissions from mobile sources on small roads for which traffic counting data is not available.

$$\text{Area source VKT} = \text{total source VKT} - \text{line source VKT}$$

2.2. Emissions Inventory in the Domestic Sector

from the domestic sector are generated from fuel combustion activities, namely from the use of LPG fuel. The calculation requires data on LPG consumption as well as population distribution and emission factors, which can be formulated as follows (BPLH DKI Jakarta, 2009):

$$E_i = \sum_{c=1}^{n} (Ac.EFci)$$

Description:

E_i = pollutant emission from households (kg /year)
A_c = fuel consumption for the household sector (kL/year for kerosene and tons/year for LPG)
EF_{ci} = pollutant emission factor/for fuel (kg/kL for kerosene and kg for LPG)

Table 2. Domestic source emission factors

Fuel	SO2	NOx	PM10	HC	CO	CO2	CH4	N2O
LPG	0	2.791	0.036	0.12	0.77	2909	0.231	0.005

Source: Regional Environmental Management Agency DKI Jakarta Province, 2009

2.3. Emissions Inventory in the Solid Waste Sector

Emissions from the solid waste sector generated from open burning activities In the calculation it takes data on the amount of solid waste generated and the fraction from combustion, or it can be formulated as follows:

$$Em_i = M_s \times EF_i$$

Description:

Em_i = Pollutant emission i
EF_i = Emission factor from pollution i (g/kg of burnt dry matter)
M_s = Amount of municipal solid waste burned (kg/year)

Determination of emissions from pollutants requires data on the amount of waste burned, but not all countries are available. If not available, it can be calculated using the following formula:

a. Open burning of waste at source

$$M_s = Pc \times P_{frac} \times MSW_{GR} \times \delta \times \eta \times 365$$

Description:

M_s = amount of waste burned (kg/year)
Pc = population (capita)
$Pfrac$ = fraction of the population burning waste
MSW_{GR} = waste generation factor per capita (kg.waste/capita.day)
δ = fraction of combustible waste
η = combustion/oxidation efficiency (fraction)

b. Open burning in landfills

$$M_s = Pc \times MSW_{GR} \times \varepsilon \times \delta \times \eta \times 365$$

Description:

M_s = the amount of waste burned (kg/year)
Pc = population (capita)
MSW_{GR} = waste generation factor per capita (kg.garbage/capita.day)
δ = fraction of combustible waste
η = combustion/oxidation efficiency (fraction)
ε = waste collection efficiency (fraction discarded/hoarded per total waste generated)

The waste generation factor per capita (MSWGR) in Indonesia has a value of 1.0 (kg/capita.day). For Pfrac value in developing countries, it can be estimated roughly based on the number of people whose waste is not collected and the number of people whose waste is collected but dumped in open dumps and then burned. The value of for complete combustion and incinerator is 1. While in open combustion the waste fraction (δ) is 0.58. Then the combustion emission factor can be seen from the following table:

Table 3. Emission factors from burning waste

Parameters	(g/kg)
SO_2	0.5
NOx	3
CO	42
PM_{10}	30

Source: United Nations Environment Program, 2013

2.4. Emission Load Prediction

The projection calculation is used to find out the emission predictions in the coming year. The data used as the basis for calculating projections until 2030 are data sourced from 2016 to 2020. In the determination, three approach methods are used, namely the arithmetic, geometric, and least square methods. The projection method chosen is based on the value of r which is close to one and has the lowest standard deviation.

2.5. Emission Reduction Strategy

The reduction strategy is carried out as a form of controlling air pollution in Salatiga City, especially for the transportation, domestic, and solid waste sectors. In its determination, SWOT analysis is used to determine the position of the strategic quadrant.

3. Results and Discussion

3.1. Emissions Inventory in the Transportation Sector

a. Line Source Emission

The line source VKT on each main road segment is calculated by multiplying the traffic volume of passing vehicles by the length of the road. Volume of the vehicle was calculated using traffic statistics obtained from the Salatiga Municipal Department of Transportation. The resulting CO emission load is 1,474.34 tons/year, NOx is 30.54 tons/year, PM_{10} is 25.27 tons/year, and SOx is 0.84 tons/year. Motorcycles are the largest contributor to pollution because the number of these vehicles is the most among other types of vehicles.

b. Total Source Emissions

Total source emission aims to determine the entire emission load generated from land transportation sources in Salatiga City. The total source VKT calculation is obtained by multiplying the number of vehicles with the average trip length or motor vehicle odometer. The resulting CO emission load is 7,104.26 tons/year, NOx is 147.16 tons/year, PM_{10} is 121.79 tons/year, and SOx is 4.06 tons/year. Motorcycles are the biggest polluter because the number of these vehicles is the most among other types of vehicles.

c. Area Source Emissions

Area source VKT calculation is obtained from the difference between the total source VKT, and the line source VKT. The resulting CO emission load is 5,629.92 tons/year, NOx is 116.62 tons/year, PM_{10} is 96.51 tons/year, and SOx is 3.22 tons/year.

d. Emission Prediction

Emission prediction is used to determine the emissions produced in the next 10 years, so that it can be used as material for determining the strategy to be used. Emissions prediction for the transportation sector emission load uses a projection of the number of vehicles based on the vehicle growth rate. In 2030, it was found that the domestic sector contributed to SOx emissions of 0 kg/year, NOx of 15,926.44 kg/year, CO of 4,393.89 kg/year, and PM_{10} of 205.43 kg/year.

3.2. Emissions Inventory in the Domestic Sector

a. Calculation of Fuel Consumption

The calculation of the average consumption of LPG is grouped based on the level of family welfare. The level of family welfare affects the use of LPG and can describe the capacity of a household. According to Marlena (2018), the average LPG consumption requirement for lower-level families is 5.83 kg/month/headquarters and for middle-class families, it is 9.34 kg/month/headquarters. The number of families is determined with the assumption that one family consists of four people (Suryo, 2017). Meanwhile, for the level of welfare in 2020, 5% of the population is a pre-prosperous community. This figure has decreased, and produced in 2030, there are only 4.4% of the underprivileged or pre-prosperous. The number of families is then multiplied by the consumption of LPG per month.

b. Emission Calculation

The emission calculation is generated by multiplying the fuel consumption with the emission factor. The result is that the domestic sector produces sulfur dioxide (SO_2) emissions of 0 kg/year, nitrogen oxides (NOx) of 14,755.53 kg/year, and carbon monoxide (CO) of 4,070,86 kg/year, and particulate matter (PM_{10}) of 190,326 kg/year.

c. Emission Prediction

Emission prediction is used to find out the emissions produced in the future, so that it can be used as material for determining the strategy to be used. In 2030 it was found that the domestic sector contributed to SOx emissions of 0 kg/year, NOx of 15,926.44 kg/year, CO of 4,393.89 kg/year, and PM_{10} of 205.43 kg/year.

3.3. Emissions Inventory in the Solid Waste Sector

a. Amount of Combustible Solid Waste

The amount of combustible solid waste is categorized into two, namely the results of open burning of waste at the source and open burning of waste at the disposal site. For open burning of waste at the source, it is calculated from:

$$M_s = Pc \ x \ P_{frac} \ x \ MSW_{GR} \ x \ \delta \ x \ \eta \ x \ 365$$

Meanwhile, open burning of solid waste in landfills is produced from:

$$M_s = Pc \ x \ MSW_{GR} \ x \ \mathcal{E} \ x \ \delta \ x \ \eta \ x \ 365$$

Description:

M_s = amount of waste burned (kg/year)
Pc = population (capita)
P_{frac} = Per capita MSW generation factor (kg waste/capita.day)
MSW_{GR} = Per capita MSW generation factor (kg waste/capita.day)
δ = Fraction of combustible MSW
η = Burning/oxidation efficiency (fraction)
$\mathcal{E}$ = MSW collection efficiency (the fraction that is dumped/land filled per total waste generated)

From these calculations, it is concluded that in 2020 there will be 4,145,752.68 kg/year of combustible waste at the source and 7,011,504.00 kg/year for open burning of waste at the disposal site.

b. Emission Calculation

Emission calculations are made by multiplying the amount of combustible waste by an emission factor. The result was emissions from the waste sector of 3,653,071.85 g/year of sulfur dioxide (SO_2), 21,918,429.85 g/year of nitrogen oxides (NOx), and 306,858.017.94 g/year of carbon monoxide (CO). years, and particulate matter (PM_{10}) of 219,184,298.53 g/year.

c. Emission Prediction

Emission prediction is used to find out the emissions produced in the future, so that it can be used as material for determining the strategy to be used. In 2030 it was found that the domestic sector contributed to SOx emissions of 3,492,879 g/year, NOx of 20,9572,775 kg/year, CO of 293,401,846 kg/year, and PM10 of 209,572,747 kg/year.

3.4. Capacity

The calculation of the capacity is carried out using the box model method. This method is used to estimate the average pollutant concentration in an area which is described as a box which means the emission sources are spread evenly on the surface under the city. Then the pollutant source will be carried and distributed from the source according to the direction of the wind. The results of the calculation of the capacity for the transportation sector are that in 2020 Salatiga City can still accommodate air pollution loads from conventional air emissions of SOx of 19.54 g/m^3, NOx of 27.60 g/m^3, CO of 8,806.15 g/ m^3, PM10 is 24.11 g/m^3. Meanwhile for the domestic sector, SOx is 33.03 g/m^3, NOx is 42.35 g/m^3, CO is 88455 g/m^3, and PM10 is 25 g/m^3 and for the solid waste sector is SOx 33.01 g/m^3, NOx 42.3 g/m^3, CO 88554 g/m^3, and PM10 24$\mu g/m^3$.

3.5. Planning of Emission Reduction Strategy

Strategic plan for reduction as a form of air pollution control in Salatiga City. SWOT analysis is used to determine the position of the strategy that has been prepared. In the transportation sector, the planned strategy is to increase public green open space by up to 20%. This is because the proportion of public green open space in Salatiga City has not been fulfilled, which is 5.97% of the minimum 20% requirement according to Law Number 26 of 2007. In addition, it is planned to build an Intelligent Transportation System (ITS) in stages on the main roads of Salatiga City. or roads with the potential for congestion and emission tests for private vehicles, cars, and motorcycles. The results of the SWOT analysis for the transportation sector obtained a quadrant II position (positive, negative), which requires more mature strategic planning. In the domestic sector, the planned strategy is the substitution of LPG fuel with organic waste biogas and the substitution of LPG fuel with livestock manure biogas. The strategy is then analyzed based on the value of strengths, weaknesses, threats, and obstacles. After that, the scoring is done and the x and y values will be generated, which are then drawn in quadrants. The result is that the strategy is in quadrant I (positive, positive) because it has strong opportunities and strategies. The organic waste biogas strategy can reduce emissions by 0.17% in 2030. Then for livestock manure biogas, it can reduce emissions by 0.142% in 2030. Then for the waste sector, the planned strategy is community empowerment in waste reduction and optimization of waste facilities. The strategy of community empowerment in reducing waste can reduce emissions by 5.2% in 2030. Meanwhile, the strategy for optimizing waste facilities can increase the service level of Salatiga City. The results of the SWOT analysis of community empowerment strategies in reducing waste and optimizing waste facilities obtained quadrant I (positive, positive) positions because they have strong opportunities and strategies.

4. Conclusion

The results of the conventional air inventory show that the emission burden of the transportation sector in 2020 for SOx is 121.06 tons/year, NOx is 2,615.51 tons/year, and CO is 18,040.89 tons/year, and PM10 is 299.66 tons/year. The domestic sector in 2020 for parameters sulfur dioxide (SO_2) of 0 kg/year, nitrogen oxides (NOx) of 14,755.53 kg/year, carbon monoxide (CO) of 4,070,86 kg/year, and particulate matter (PM10) of 190,326 kg/year. As for the waste sector in 2020, the parameters for sulfur dioxide (SO_2) are 3,653,071.85 g/year, nitrogen oxides (NOx) are 21,918,429.85 g/year, carbon monoxide (CO) is 306.858,017.94 g. /year, and particulate matter (PM10) of 219,184,298.53

g/year. The planned strategy for the domestic sector is the substitution of LPG fuel with household organic waste biogas and livestock manure biogas. Organic waste biogas can reduce emissions by 0.17% in 2030. Then the biogas used for livestock and poultry manure can reduce emissions by 0.142% in 2030. Then for the waste sector, the planned strategy is community empowerment in waste reduction and optimization of waste facilities. The strategy of community empowerment in reducing waste can reduce emissions by 5.2% in 2030. Meanwhile, the strategy for optimizing waste facilities can increase the service level of Salatiga City. Emissions reduction from the transportation sector is planned as a strategy in the form of increasing the proportion of public green open space to reach 20%, building it, and implementing exhaust emission tests for private vehicles in the car and motorcycle categories. The results of the SWOT analysis for the domestic and solid waste sectors are quadrant I (positive, positive) because they have strong opportunities and strategies, while for the transportation sector, quadrant II (positive, negative) positions are needed, which requires more mature strategic planning.

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