JPII 11(2) (2022) 260-270

Jurnal Pendidikan IPA Indonesia

http://journal.unnes.ac.id/index.php/jpii

ANALYSIS OF INDONESIA'S THREE MAJOR ANTHROPOGENIC POLLUTANTS WHICH INCLUDE VARIOUS EMISSION AND FUEL SECTORS IN THE 1990-2015 PERIOD

S. Sunarno*[1,4], P. Purwanto[1,2], B. Warsito[3]

[1]Green Technology Research Center (GreenTech), Doctorate Program of Environmental Science, School of Postgraduate Studies, Universitas Diponegoro, Semarang, Indonesia
[2]Department of Chemical Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia
[3]Department of Statistics, Faculty of Science and Mathematics, Universitas Diponegoro, Semarang, Indonesia
[4]Department of Physics, Faculty of Science and Mathematics, Universitas Negeri Semarang, Semarang, Indonesia

DOI: 10.15294/jpii.v11i2.33224

Accepted: November 8th 2021. Approved: June 27th 2022. Published: June 30th 2022

ABSTRACT

The rapid industrial growth and urbanization in Indonesia over the last two decades have resulted in a significant increase in air pollution, so it has caused a decrease in air quality. An air pollution inventory is needed to determine the level of air quality, emission sector, and the type of pollutant fuel. Air pollutant emission data were obtained from various sources, including Regional Emissions Inventory in Asia (REAS) V3.1, Database Emissions for Global Atmospheric Research (EDGAR) V4.3.2, and Community Emissions Data System (CEDS) V1.0. The data consists of 3 types of emitted pollutants (CO, NO_X, and SO_2) and two contributing factors (emission and fuel sectors). This study aims to compare data from the emission sources of the three air pollutants, determine the trend of changes in the emission of the three pollutants, and determine the main sectors and fuels that emit the three air pollutants. This research uses the literature study method to collect, visualize, and analyze data. The results showed that between 2005 and 2012, there was a downward trend in emissions in the industrial sector for CO, NO_X, and SO_2 gases, with the lowest point in August. This is because many industrial sectors have applied the principle of clean energy to reduce air pollution and create clean air. However, the transportation sector showed an increase in CO and NO_X emissions and peaked in April and October. Furthermore, the SO_2 emissions for the power generation sector fluctuated and peaked in July.

Keywords: air pollutants; anthropogenic emissions; global inventory

INTRODUCTION

Environmental problems have become an important issue in global discussions, including ozone layer damage (Sivasakthivel & Reddy, 2011). Air pollution is one of the factors that cause damage to the ozone layer and has the potential to destroy life and directly impact health and environmental damage (Manisalidis et al., 2020). Air pollution is caused by two factors: natural (volcanic activity, oceans, forests, and others) and human activity (burning of fossil fuels, transportation, emissions from the power generator, industry, residential, and others). Anthropogenic emissions (caused by human activities) increase the rate of human mortality (Lelieveld et al., 2019) and morbidity, as well as affect terrestrial and marine ecosystems (Hoesly et al., 2018).

Air pollutants are emitted as gaseous compounds (NOx, SO_2, CO, CO_2, and NMVOC), BC, OC, NH_3, and particulates such as PM10 and PM2.5. Polluted air results in poor air quality, which occurs in many local, regional, and global regions with high pollutant levels. In many countries, CO, NO_X, and SO_2 gases are pollutants that contribute to relatively large levels of air

***Correspondence Address**
E-mail: narnofisika91@gmail.com

pollution. In China, India, Central Asia, North America, and Europe, these three types of pollutants contribute significantly to air pollution in their countries (Crippa et al., 2018; Kurokawa & Ohara, 2019). The cities of Bandung, Jakarta, Medan, Semarang, and Surabaya also show that these three pollutants rank 1st, 2nd, and 3rd out of 5 pollutants (Hydrocarbons, CO, NO_2, SO_2, and particulates) that contribute to high air pollution. in Indonesia (Sunarno et al., 2021)

Global emission inventories and local air pollution measurements are very helpful in providing information about the air quality in a region. In recent years, global emission inventories have been developed, such as EDGAR (Emissions Database for Global Atmospheric Research), REAS (Regional Emissions inventory in Asia), CEDS (the Community Emissions Data System) (Mcduffie et al., 2020), HTAP (Hemispheric Transport of Air Pollution) (Janssens-Maenhout et al., 2015), and ECLIPSE (Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants) (Klimont et al., 2017). All sources of emission data inventory of air pollution, which provides ten types of air pollutants (NO_x, SO_2, CO, CO_2, NMVOC, BC, OC, NH_3, PM10, and PM2.5), are obtained from polluting sectors: power generators, transportation, settlements, industry, domestic and others, as well as from fuel combustion such as primary coal, diesel motor oil, light, and heavy fuel oil, biofuel and others (Janssens-Maenhout et al., 2015)

No studies have been conducted in Indonesia to compare emission data from EDGAR, REAS, and CEDS sources. Comparison of air emission data between various sources, mostly carried out by researchers in several regions, including North America, China, and Europe (Klimont et al., 2013; Shi et al., 2015). This comparison is used to determine the accuracy and deviation of the resulting data. To fill this gap, this research compares the estimates of Carbon Oxide (CO), Nitrogen oxides (NOx), and sulfur dioxide (SO_2) for 1990 - 2015 reported by REAS with similar estimates from EDGAR and CEDS.

REAS V3.1 provides historical data on emissions of air pollutants for a relatively long time between 1950-2015 in ASIA. Meanwhile, Indonesia has a high level of air pollution in Southeast Asia, especially for the three types of pollutants: CO, $NO_{X,}$ and SO_2. This is due to rapid population growth, industrialization, urbanization, and economic growth, so the air pollution problem is increasing rapidly (Sunarto et al., 2017). For analysis, 26 years of data, from 1990 to 2015, were obtained from REAS, EDGAR V4.3.2, and CEDS V1.0. In general, these data are provided for each country annually. The monthly data are specifically provided by the European Commission, Joint Research Center (JRC) / PBL Netherlands Environmental Assessment Agency. EDGAR,v4.3.2. (EC-JRC/PBL, 2019).

This study aims to compare and analyze data between 3 global inventories, determine the annual emission levels of the three types of pollutants (CO, NO_X, and SO_2), and analyze the causative factors and the changes in patterns and trends of emission monthly and annually. Indonesia requires long-term observations of air pollutant emissions to determine trends and distribution patterns and as a medium for policymakers to evaluate the effectiveness of air pollution control strategies and long-term air quality management.

In previous studies, many studies on the evolution of global and regional anthropogenic SO_2 emissions in the last decade in China (Klimont et al., 2013; Liu et al., 2018), a mosaic Asian anthropogenic emission inventory using data from the MICS-Asia and HTAP (Li et al., 2017), Changes in NOx and O_3 concentrations over a decade at a central urban area of Seoul, Korea (Vellingiri et al., 2015). Intercomparison of NOx emission inventories over East Asia (Ding et al., 2017) and Long-term (2005–2015) trend analysis of PM2.5 precursor gas NO_2 and SO_2 concentrations in Taiwan (Lee et al., 2018). However, research comparing three inventories of air pollution data with three types of pollutants in Indonesia has never been done.

METHODS

This research adopted a literature study approach by collecting secondary data from several sources of global emission data providers, including the Emissions Database for Global Atmospheric Research (EDGAR), released EDGAR v4.3.2 (1970 – 2012) in March 2016, http://edgar.jrc.ec.europa.eu, 2016, Regional Emission inventory in Asia (REAS). The latest version of REASv3.1 provides an extended historical emission inventory in Asia from 1950 to 2015. The same applies to the Community Emission Data System (CEDS) version tag: 2020_v1.0 (April 2020) and the Indonesian Central Bureau of Statistics (BPS). The emission data provided by EDGAR, REAS, and CEDS were obtained using the Bottom-Up Methodology (Liu et al., 2018; Janssens-Maenhout et al., 2019).

This research is focused on air pollution in Indonesia. This study only focused on three types of emissions: CO, NO_X, and SO_2. These pollutants show relatively high emission levels. Therefore, a more in-depth analysis is needed to reveal how these conditions occurred. Besides limiting the types of emissions, the time interval for data collection was also limited to 2.5 decades (1990-2015). Figure 1 shows the research flow.

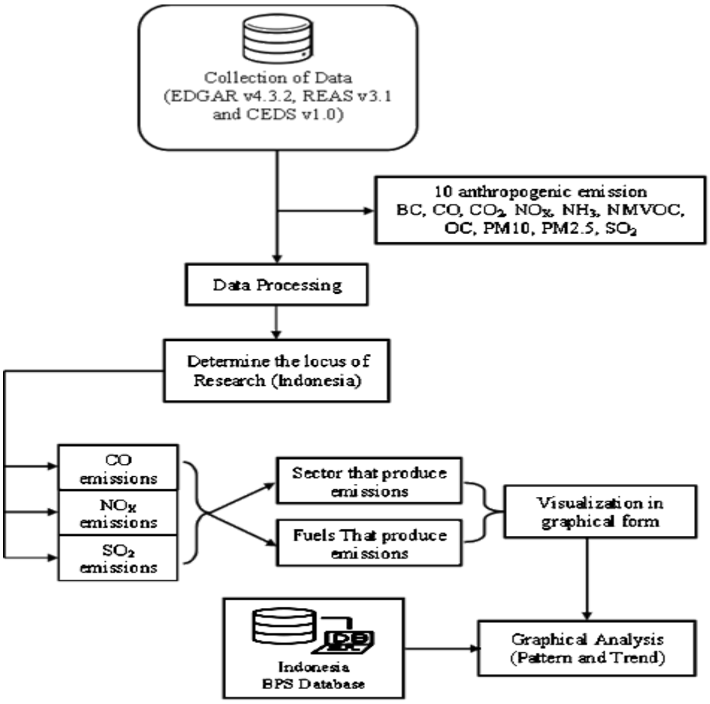


Figure 1. Research Flow Chart

This research procedure was carried out in several stages: (1) download data from sources that provide air pollution data, namely EDGAR, REAS, and CEDS; (2) determine the selected location and type of emission. This research is focused on air pollution in Indonesia. This research only focused on three types of emissions: CO, NO_X, and SO_2; (3) create a data display in a graph. The data is made in a graphical display, with the x-axis being the time (years) and the y-axis being the pollutant concentration (kton/year); (4) compare various aspects of data from the three sources. Some aspects to consider are Temporal Coverage, Type of pollutant, Number of Sectors, Detailed Fuels, and Spatial Resolution; (5) analyze trends in CO, NOx, and SO_2 gas emissions for emitting sectors and fuels. REAS v3.1 provides six types of anthropogenic emission-producing sectors: Power Plant Point (PP), Industry (IND), Other Domestic (ODOM), Road Transportation (ROAD), Other Transportation (OTRA), and Residential (RESI). Five out of six available sectors were selected for this study except OTRA, because of its low data emission compared with other sectors.

Meanwhile, REAS v3.1 also provides data on 11 types of fuels. Depending on the type analyzed, this study selected six to seven types. For CO emissions, there are six types of analyzed fuels: Bio Fuel (BF), Light Fuel (LF), Primary Coal (COAL), Motor Diesel Oil (MD), Non-Combustion Oil (NCMB), and Natural Gas (NGAS). NO_X is equal to CO, but it replaces NCMB with Heavy Fuel Oil (HF). SO_2 is equal to CO and only replaces NGAS with HF. The choice of fuels for each emission depends on the size emitted. Therefore, the pattern or trend drawn on the graph is easy to analyze.

Furthermore, the obtained data is visualized in graphical form in relationship lines between variables, bar charts, and pie charts. This graphic visualization is constructive for viewing the patterns or trends over time and the causality relationship between the graph in the emitting sector and its fuel emission. In conclusion, Indonesia's BPS data is essential for visualization analysis.

RESULTS AND DISCUSSION

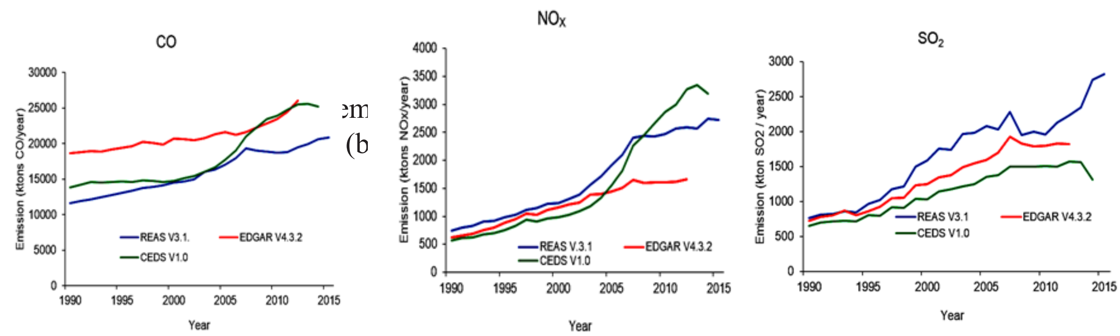
This research data were obtained from several sources, including REAS V3.1, EDGAR V4.3.2, and CEDS GBD MAPS 2020 V1.0. The three data sources possess different characteristics, as shown in Table 1. Data collection for the three inventory sources was carried out at different periods. Table 1 shows that EDGAR has advantages over other sources compared to the three parameters. Its advantages are the smaller spatial resolution and the much larger number of fuel and emission-generating sectors collected (Janssens-Maenhout et al., 2019). The other sources (REAS and CEDS) only have better temporal coverage parameters. The parameters compared from the three sources are only metadata, not the content or type of pollutant. We cannot decide that EDGAR is the best for concentration data, and further analysis should be carried out.

For comparative analysis, 26 years were selected, starting from 1990 to 2015. The results of the comparison are shown in Figure 2. It shows the comparison result of REAS V3.1 with two other sources: EDGAR V4.3.2 and CEDS V1.0. Before 1995, the trend of SO_2 emission in Asia from the three inventory sources has no significant difference (Kurokawa & Ohara, 2019). Likewise, in Indonesia, the emissions of SO_2 and NO_X before 1995 were relatively similar. However, the SO_2 emission from REAS V3.1 data showed an increase from 2007, while EDGAR V4.3.2 showed a constant value and CEDS V1.0 tended to decrease. Meanwhile, the CEDS data for NO_X emissions after 2007 increased significantly. For CO emissions, prior to 2007, the REAS V3.1 and EDGAR V4.3.2 data had a significant difference, with the 16.06% as the highest. In general, this indicates an increasing trend of emissions from various types of pollutants at the global level (Mcduffie et al., 2020).

Table 1. The Comparison of Three Emission Inventory Sources of Air Pollutants

Inventery name (version)	Temporal Coverage	Type of pollutans	Number of Sector	Detailed Fuels	Spatial Resolution
EDGAR v4.3.2	1970 – 2012	BC, CO, CO_2, NH_3, NMVOC, NO_X, OC, PM2.5, PM10, and SO_2	12 to 18	Total only	0.1^0 x 0.1^0
REAS v3.1	1950 – 2015	BC, CO, CO_2, NH_3, NMV, NO_X, OC, PM2.5, PM10, and SO_2	6	Total coal, Liquid Fuel, Biofuel, and Gas Fuel	0.25^0 x 0.25^0
CEDS GBD MAPS 2020 v1.0	1750 – 2014	NO_X, SO_2, CO, NH_3, NMVOCs, BC, and OC	11	Total coal, Solid Fuel, Biofuel, and Liquid Fuel	0.5^0 x 0.5^0

Indonesia's yearly emissions of three different data sources with CO, NO_X, and SO_2 pollutants from 1990 to 2015 are shown in Figure 2.



(a) (b) (c)

Figure 2. Indonesia's Yearly Emissions of Three Data Sources from 1990 to 2015: (a) CO Pollutant, (b) NO_X Pollutant, and (c) SO_2 Pollutant

A comparison of the data sources for each pollutant (SO2, NO_{X}, and CO) in 2012 is in Figure 3. Many researchers often make comparisons of air emission data from several inventory sources (Janssens-Maenhout et al., 2015). Figure 3 shows the difference in the presentation of CO compounds between EDGAR V4.3.2 and CEDS V1.0 by 0.8%, while for REAS V3.1, it differs by 8.5% - 9.2% from the other two data sources. Meanwhile, for SO2, EDGAR V4.3.2 and CEDS V1.0 was only 4.4%, while for REAS V3.1, the difference ranges from 7.3% to 11.7% with the other two data sources. In contrast to the NOX compound, which shows a significant difference, where the percentage difference between REAS V3.1 and CEDS V1.0 is 9.0%, while EDGAR V4.3.2 has a difference ranging from 12.4% to 21.4% compared to the other data sources. Differences in data from each source can be caused by several factors, including different accuracy and grid maps of the equipment used, different assessment standards, and human error. Therefore, if it is compared, there is data that reads higher or lower.

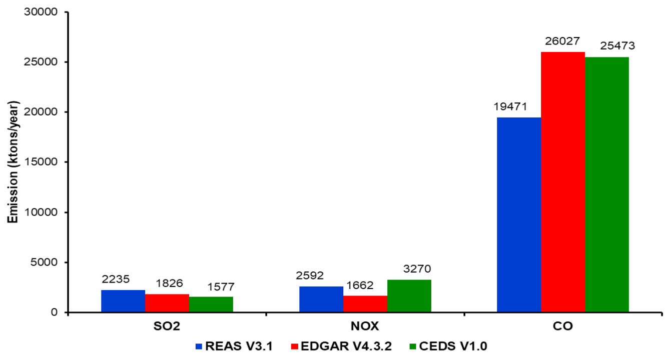
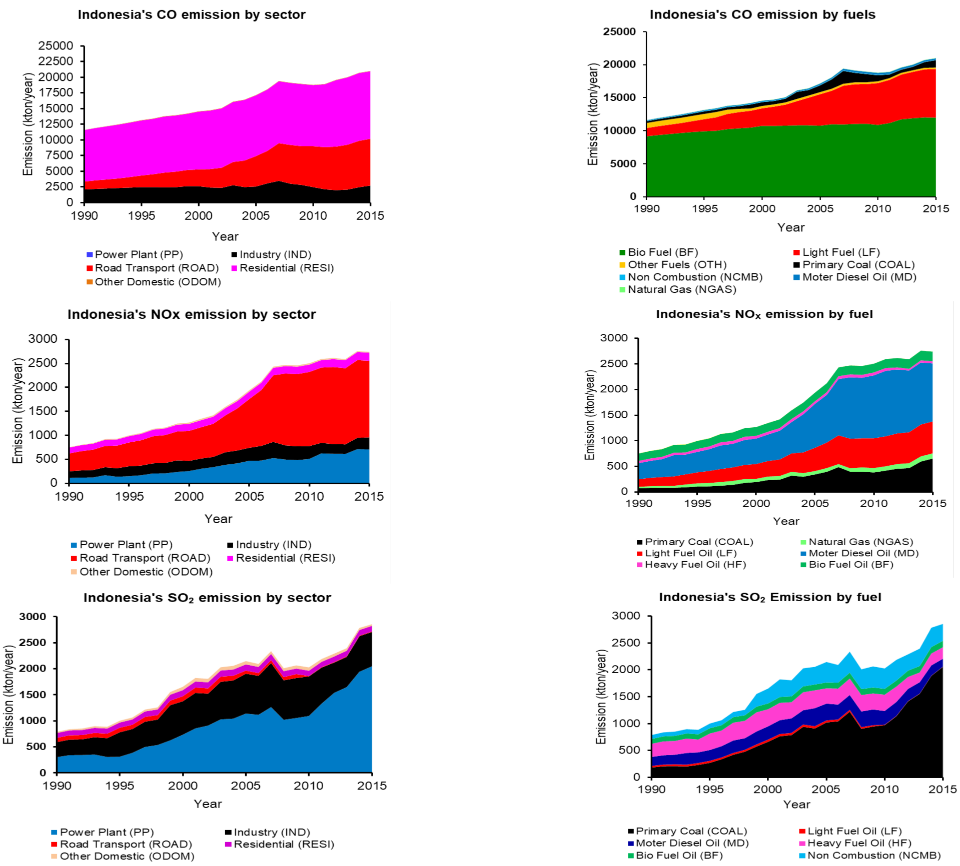


Figure 3. The Comparison Graph of Three Inventory Sources for Three Air Pollutants in 2012

The analysis result of three pollutant emissions from 1990 to 2015 based on REAS V3.1 data for the polluting sector and the type of fuel are in Figure 4.

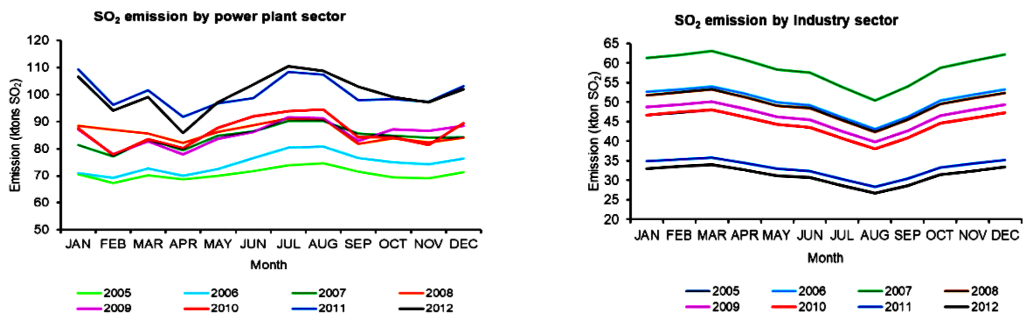


(a) (b)

Figure 4. Indonesian Air Pollutants from1990 to 2015: (a) by sector and (b) by fuel

In many countries, steam power generation and industry contribute the most extensive levels of SO_2 pollution (Ohara et al., 2007; Kurokawa & Ohara, 2019). Figure 4 shows that, in 2015, the power generation sector contributed around 71.70%, the industrial sector 23.07%, and the rest was generated by transportation, housing, and other domestic sectors. Steam power plants and many industries use coal as their energy source, so their activities produce SO_2 gas pollution. For fuel emissions, coal is the most significant contributor (Sudalma et al., 2015), as it emits 72.06% of SO_2, 10.96% of non-combustion (NCMB), 7.46% of heavy fuel oil, 5.16% of diesel motor oil, and the rest is contributed by bio and light fuel. Furthermore, the coal-fired power station (also known as PLTU in Indonesia) generates the most significant SO_2 emissions. In 2015, its installed power capacity reached 21087.15 MW, or around 53.1% of the total power generation (Badan Pusat Statistik (BPS), 2020).

The calculation of emission data per month of each country is provided by the European Commission, Joint Research Center (JRC)/PBL Netherlands Environmental Assessment Agency, EDGAR, v.4.3.2 http://edgar.jrc.ec.europe.eu. To distribute monthly to annual emissions, all countries were grouped into 23 regions with profiles based on climate, ecology, and degree of warming zones (Crippa et al., 2020). From data collected from JRC, the analysis of SO_2 emissions in Indonesia per month is presented in Figure 5.



(a) (b)

Figure 5. Indonesian SO_2 Emissions from 2005 to 2012: (a) by power plants and (b) by industry sector

Figure 5(a) shows the monthly change (fluctuation) of SO2 emissions. Emission started in January, peaked in July, and afterward, it experienced a decline. This high production requires the burning of large amounts of coal. Therefore SO_2 emissions in July are the highest. In the industrial sector, as in Figure 5(b), there is a reduction in overtime SO_2 emissions which shows a decrease in the use of coal for production purposes. In August, SO_2 emission and production activities decreased significantly due to the celebration of Independence Day. The reduction in production activities will decrease the amount of pollution generated by the industrial sector. The trend of decreasing SO_2 emissions also occurs in many regions, including Europe, North America, and East Asia (Aas et al., 2019).

The results showed a very close relationship between NO_X emissions and pollution caused by motor vehicle fumes (Vellingiri et al., 2015). Over time, in many countries, transportation and its problems (number, ratio of vehicles to year of manufacture, and condition) are the significant causes of air pollution problems (Zhang et al., 2016). Figure 4 shows the increase in NO_X emission for all sectors from 1990 to 2007. However, after 2007, the industrial, residential and other domestic sectors stagnated and tended to decline, while the transportation and power generation sectors continued to rise despite being relatively skewed.

In Indonesia, the transportation sector has the largest NO_x emissions, contributing around 58.26% in total, 25.75% from the power generation sector, 9.23% from the industrial and the rest from the residential and others. Figure 6 shows the monthly emission data of the three main sectors producing NOX emissions in detail.

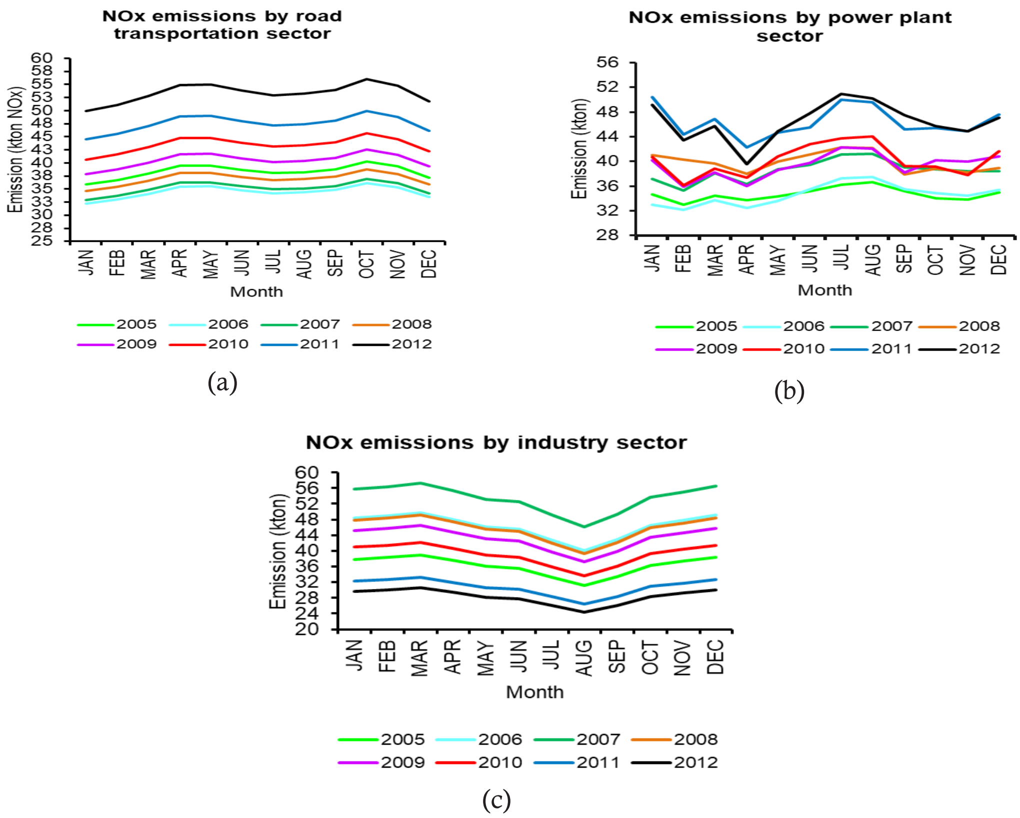


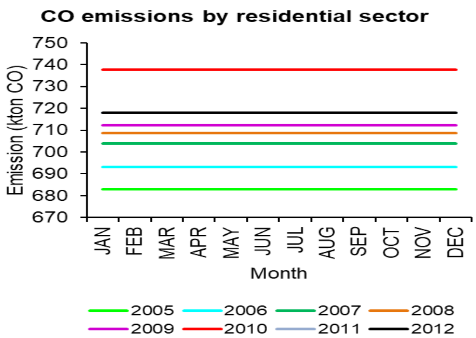
Figure 6. Indonesian NO_X Emission from 2005 to 2012: (a) by road transportation, (b) by power plan, and (c) by industry

Figure 6 shows the increase in emissions by the transportation sector with two peaks in April and October from 2009 to 2012. The power generation sector also shows the same data. However, there is a fluctuation for each month. The peak of NO_X emissions for the power generation sector is in July, in contrast to the industrial sector, which declines each year and shows the same pattern. However, in August, it decreases significantly. From data from the Indonesian Central Statistics Agency (BPS), July is the peak month of electricity production because, as a reserve to support Indonesia's Independence Day activities in August, it caused NO_X gas emissions to increase. While for industry, there is a decrease in production activities in August because of Indonesian Independence Day activities. Other than the polluting sector, fuel use also has a significant impact. Diesel motor oil provides approximately 41.3% of NO_X emissions, primary coal is 23.8%, light fuel oil is 22.7%, and the rest is provided by biofuel, natural gas, and heavy fuel oil. Furthermore, the transportation sector's contribution to NO_X emissions is related to the number of vehicles and type of fuel. In Belgrade, this shows that diesel and CNG fuel use in buses still produce relatively high NO_X emissions (Tica et al., 2019).

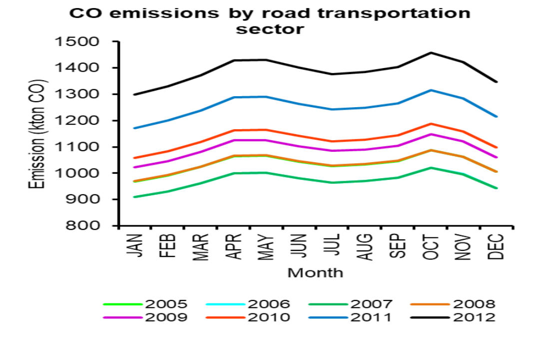
In many European countries, including the USA and China, transportation and housing are the main sectors contributing to CO emissions (Crippa et al., 2018; Tica et al., 2019; Mcduffie et al., 2020). Emissions from the residential sector depend on the amount of burnt waste, composition, and burning conditions (Hoesly et al., 2018). Figure 3.3 shows that three main sectors contribute to the emission of carbon monoxide (CO), including residential, transportation, and industry. However, the industrial sector has relatively constant CO emissions and tends to decline after 2007, in contrast to the other sectors, which tend to increase. Furthermore, in 2015, the residential sector provided around 51.26% of CO emissions, while the transportation and industrial were around 35.55% and 12.52%, respectively. The rest was provided by the power plant and other domestic sectors. In conclusion, Figure 7 shows the monthly CO emission data of the three main sectors in detail.

For all emissions, the industrial sector shows the same tendency as it continuously decreases yearly, and there is a significant decrease in August. For CO emissions, the lowest value is still more significant than the other two. Also, NO_X and CO emissions in the transportation sector have a similar pattern, with peaks in April and

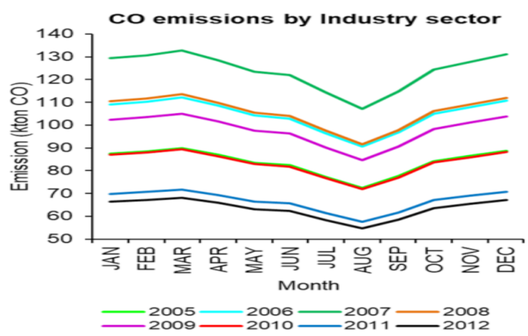
October. Even though it has the same pattern, it has different emission values. Meanwhile, the residential sector has a constant value for each month. Furthermore, Figure 7(a) shows the trend of reducing CO emissions from the residential sector annually due to the energy conversion policy from non-LPG to LPG. Therefore there is a downward trend in CO emissions in this sector.



(a)



(b)



(c)

Figure 7. Indonesian CO Emission from 2005 to 2012: (a) by residential, (b) by road transportationand (c) by industry

Residential activities that cause air pollution are burning wood as fuel or heating in cold seasons (Kurokawa & Ohara, 2019). Other than the emitting sector, the use of different types of fuels such as biofuel, light, and primary coal is also a significant factor in the emission of CO. Furthermore, oil from biofuel contributed around 57.08% of CO emissions, light fuel oil, and primary coal are 34.99% and 5.33% respectively, and the rest came from diesel motor oil and natural gas. In Indonesia, the use of wood fuel is still relatively high, contributing significantly to CO emissions (Bari et al., 2011). Figure 8 shows the percentage of energy source utilization from 2007 to 2016, in which wood fuel and kerosene decreased while the use of LPG increased. This is due to the government's policy of converting energy sources to LPG (Badan Pusat Statistik (BPS), 2018).

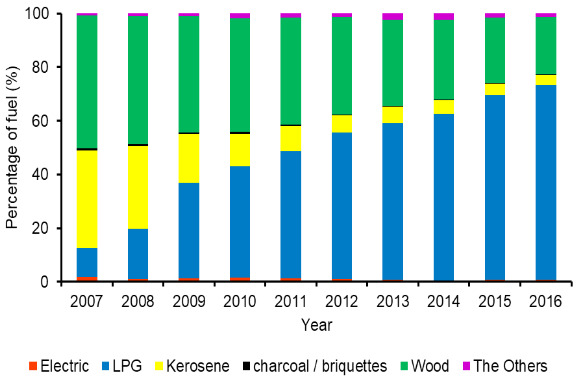


Figure 8. The Percentage of Energy Resource Use in Indonesia from 2007 to 2016 (Badan Pusat Statistik (BPS), 2018)

EDGAR V4.3.2 provides an overview map for all pollutants at the global level from 2005 to 2012. However, only three (CO, NO_x, and SO_2) were selected for this study. Figure 9 shows grid maps of total emissions for the three emission types. Figure 9 shows that CO emissions in Java, most of Sumatra and Sulawesi, and West and South Kalimantan are in the red category, while other areas are in yellow. NO_x and SO_2 emission shows relatively similar conditions. In Java, NO_x emission is categorized as slightly reddish, while for SO_2, the color is orange. Meanwhile, Sumatra is categorized as yellow, Kalimantan and Sulawesi as yellow and green, and Papua as green. This shows that Indonesia's CO emission level is greater than NO_x and SO_2. The following is the novelty of this research: (1) Information about the most complete and accurate provider of air pollution data, of which EDGAR is one of them; (2) Information on the main pollutant sectors and sources in Indonesia and their trends in the future.

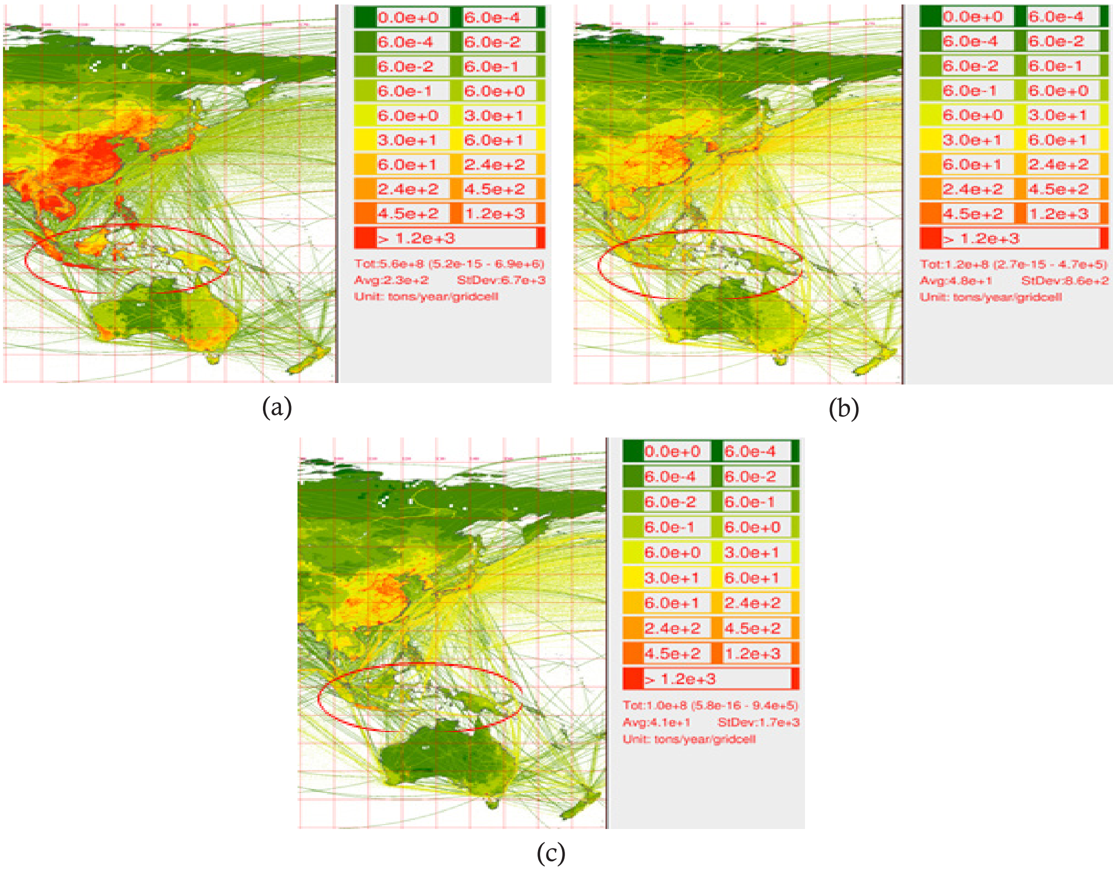


Figure 9. Indonesian Total Emission Grid Map in 2012, (a) for CO, (b) for NO_x, and (c) for SO_2 emission by EDGAR V4.3.2 (EC-JRC/PBL, 2017)

The results of this study can provide an overview of the health impacts and environmental damage that occurs if air pollution is not controlled. In addition, it will provide public awareness of the importance of clean air and a guide for effective air pollution control strategies.

CONCLUSION

The REAS V3.1 data for the emission of SO_2 and NO_x from 1990 to 2015 were consistently higher than the other two global inventories. However, after 2004, it increased significantly and in 2008 exceeded the data from REAS V3.1. Before 1995, the trend of SO2 and NOX emissions for the three global inventories was relatively similar. However, from 2007, the SO_2 emission from REAS V3.1 data showed an increase, while EDGAR V4.3.2 showed a constant value and CEDS V1.0 tended to decrease. Meanwhile, REAS V3.1 and EDGAR V4.3.2 data showed a significant difference in the emission of CO before 2007, with 16.06% as the highest. Furthermore, according to the emission patterns in the industrial, transportation, and power generation sectors depicted in the monthly data of EDGAR V.4.3.2, there is a similar pattern with different values. However, from 2009 to 2012, there was a trend of reducing emissions of CO, NO_x, and SO2, with the lowest point in August. In contrast, the transportation sector experienced an increase in emissions and peaked in April and October. This is due to a significant increase in motorized vehicles which averaged 6.9% from 2010 to 2018. Furthermore, in the power generation sector, SO_2 emissions fluctuated and peaked in July. Meanwhile, the residential sector shows a relatively constant trend of CO emissions and tends to decrease, with the same pattern every month. Furthermore, CO is an air pollutant with the highest emission level in Indonesia, with a total of 78.96% of the three emissions analyzed in 2015, while SO_2 and NO_X were around 10.73% and 10.31%, respectively. According to REAS V3.1, the residential sector emits the most CO, followed by transportation and the industrial. Meanwhile, EDGAR V4.3.2 reported that the largest CO emitter is the transportation sector, followed by the residential and industrial sectors. Furthermore, the emitting sectors strongly correlate with the type of used fuel. This is evident as the residential and transportation sectors are closely related to bio and light fuel, which are the types that emit the most CO emission with a percentage of around 57.08% and 34.99%, respectively. Finally, the power generation and primary coal sectors are the pairs that contribute the most significant SO_2 emissions, while the transportation sector and diesel motor oil emit the most NO_X.

REFERENCES

Aas, W., Mortier, A., Bowersox, V., Cherian, R., Faluvegi, G., Fagerli, H., ... & Xu, X. (2019). Global and regional trends of atmospheric sulfur. *Scientific reports*, *9*(1), 1-11.

Bari, M. A., Baumbach, G., Kuch, B., & Scheffknecht, G. (2011). Air pollution in residential areas from wood-fired heating. *Aerosol and Air Quality Research*, *11*(6), 749-757.

Badan Pusat Statistik (BPS). (2018). *The number of domestic motor vehicles in Indonesia in period 2007 - 2016*. https://www.bps.go.id./

Badan Pusat Statistik (BPS). (2020). *Generating capacity installed by power plant in Indonesia*. https://www.bps.go.id./

Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., Van Aardenne, J. A., ... & Janssens-Maenhout, G. (2018). Gridded emissions of air pollutants for the period 1970–2012 within EDGAR v4. 3.2. *Earth Syst. Sci. Data*, *10*(4), 1987-2013.

Crippa, M., Solazzo, E., Huang, G., Guizzardi, D., Koffi, E., Muntean, M., ... & Janssens-Maenhout, G. (2020). High resolution temporal profiles in the Emissions Database for Global Atmospheric Research. *Scientific data*, *7*(1), 1-17.

Ding, J., Miyazaki, K., Van Der A, R. J., Mijling, B., Kurokawa, J. I., Cho, S., ... & Levelt, P. F. (2017). Intercomparison of NO x emission inventories over East Asia. *Atmospheric Chemistry and Physics*, *17*(16), 10125-10141.

EC-JRC/PBL. (2017). *New high resolution temporal profiles in EDGAR*. Https://Edgar.Jrc.Ec.Europa.Eu/Overview.Php?V=temp_profile#.

EC-JRC/PBL. (2019). *Emission Database for Global Atmospheric Research (EDGAR), release version 4.2*. Http://Edgar.Jrc.Ec.Europa.Eu/Index.Php.

Hoesly, R. M., Smith, S. J., Feng, L., Klimont, Z., Janssens-Maenhout, G., Pitkanen, T., ... & Zhang, Q. (2018). Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS). *Geoscientific Model Development*, *11*(1), 369-408.

Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., ... & Oreggioni, G. D. (2019). EDGAR v4. 3.2 Global Atlas of the three major greenhouse gas emissions for the period 1970–2012. *Earth System Science Data*, *11*(3), 959-1002.

Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Dentener, F., Muntean, M., Pouliot, G., ... & Li, M. (2015). HTAP_v2. 2: a mosaic of regional and global emission grid maps for 2008 and 2010 to study hemispheric transport of air pollution. *Atmospheric Chemistry and Physics*, *15*(19), 11411-11432.

Klimont, Z., Smith, S. J., & Cofala, J. (2013). The last decade of global anthropogenic sulfur dioxide: 2000–2011 emissions. *Environmental Research Letters*, *8*(1), 014003.

Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., ... & Schöpp, W. (2017). Global anthropogenic emissions of particulate matter including black carbon. *Atmospheric Chemistry and Physics*, *17*(14), 8681-8723.

Kurokawa, J., & Ohara, T. (2019). Long-term historical trends in air pollutant emissions in Asia: Regional Emission inventory in Asia (REAS) version 3.1. *Atmospheric Chemistry and Physics*, 1–51.

Lee, C. S., Chang, K. H., & Kim, H. (2018). Long-term (2005–2015) trend analysis of PM2. 5 precursor gas NO2 and SO2 concentrations in Taiwan. *Environmental Science and Pollution Research*, *25*(22), 22136-22152.

Lelieveld, J., Klingmüller, K., Pozzer, A., Burnett, R. T., Haines, A., & Ramanathan, V. (2019). Effects of fossil fuel and total anthropogenic emission removal on public health and climate. *Proceedings of the National Academy of Sciences*, *116*(15), 7192-7197.

Li, M., Zhang, Q., Kurokawa, J. I., Woo, J. H., He, K., Lu, Z., ... & Zheng, B. (2017). MIX: a mosaic Asian anthropogenic emission inventory under the international collaboration framework of the MICS-Asia and HTAP. *Atmospheric Chemistry and Physics*, *17*(2), 935-963.

Liu, F., Choi, S., Li, C., Fioletov, V. E., McLinden, C. A., Joiner, J., ... & da Silva, A. M. (2018). A new global anthropogenic SO 2 emission inventory for the last decade: a mosaic of satellite-derived and bottom-up emissions. *Atmospheric Chemistry and Physics*, *18*(22), 16571-16586.

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: a review. *Frontiers in public health*, 14.

McDuffie, E. E., Smith, S. J., O'Rourke, P., Tibrewal, K., Venkataraman, C., Marais, E. A., ... & Martin, R. V. (2020). A global anthropogenic emission inventory of atmospheric pollutants from sector-and fuel-specific sources (1970–2017): an application of the Community Emissions Data System (CEDS). *Earth System Science Data*, *12*(4), 3413-3442.

Ohara, T., Akimoto, H., Kurokawa, J., Horii, N., Yamaji, K., Yan, X., & Hayasaka, T. (2007). An Asian emission inventory of anthropogenic emission sources for the period 1980-2020. *Atmospheric Chemistry and Physics*, *7*(16), 4419–4444.

Shi, Y., Matsunaga, T., Saito, M., Yamaguchi, Y., & Chen, X. (2015). Comparison of global inventories of CO2 emissions from biomass burning during 2002–2011 derived from multiple satellite products. *Environmental pollution*, *206*, 479-487.

Sivasakthivel, T., & Reddy, K. S. K. (2011). Ozone layer depletion and its effects: a review. *International Journal of Environmental Science and Development*, *2*(1), 30.

Sudalma, S., Purwanto, P., & Santoso, L. W. (2015). The effect of SO2 and NO2 from transportation and stationary emissions sources to SO42− and NO3− in rain water in Semarang. *Procedia Environmental Sciences*, *23*, 247-252.

Sunarno, S., Purwanto, P., & Suryono, S. (2021). Trend Analysis of NOX and SO2 Emissions in Indonesia from the Period of 1990 -2015 using Data Analysis Tool. *Advances in Science, Technology and Engineering SystemsJournal*, *6*(1), 257–263.

Sunarto, S., Purwanto, P., & Hadi, S. P. (2017). Quantification of greenhouse gas emissions from municipal solid waste recycling and disposal in Malang city Indonesia. *Journal of Ecological Engineering*, *18*(3), 74–82.

Tica, S., Živanović, P., Bajčetić, S., Milovanović, B., & Nađ, A. (2019). Study of the fuel efficiency and ecological aspects of CNG buses in urban public transport in Belgrade. *Journal of Applied Engineering Science*, *17*(1), 65–73.

Vellingiri, K., Kim, K. H., Jeon, J. Y., Brown, R. J., & Jung, M. C. (2015). Changes in NOx and O3 concentrations over a decade at a central urban area of Seoul, Korea. *Atmospheric Environment*, *112*, 116-125.

Zhang, S., Wu, Y., Huang, R., Wang, J., Yan, H., Zheng, Y., & Hao, J. (2016). High-resolution simulation of link-level vehicle emissions and concentrations for air pollutants in a traffic-populated eastern Asian city. *Atmospheric Chemistry and Physics*, *16*(15), 9965-9981.