ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol.52 , No. 1, 2020 (1–7)
DOI: http://dx.doi.org/10.22146/ijg.48802 website: https://jurnal.ugm.ac.id/ijg
©2020 Faculty of Geography UGM and The Indonesian Geographers Association

INDONESIAN JOURNAL OF GEOGRAPHY

Research Article

Greenhouse Gas Pollution Based on Energy use and its Mitigation Potential in the city of Surakarta, Indonesia

Prabang Setyono[1], Widhi Himawan[1], Cynthia Permata Sari[1], Totok Gunawan[2] and Sigit Heru Murti[2]
[1]Faculty of Mathematics and Natural Science, Universitas Sebelas Maret, Indonesia.[2] Faculty of Geography, Universitas Gadjah Mada, Indonesia.

Received: 2019-08-25
Accapted: 2020-03-13

Keywords:
energy;
greenhouse gas (GHG);
vegetation;
Surakarta.

Correspondent email:
prabangsetyono@gmail.com

Abstract Considered as a trigger of climate change, greenhouse gas (GHG) is a global environmental issue. The City of Surakarta in Indonesia consists mainly of urban areas with high intensities of anthropogenic fossil energy consumption and, potentially, GHG emission. It is topographically a basin area and most likely prompts a Thermal Inversion, creating a risk of accumulation and entrapment of air pollutants or GHGs at low altitudes. Vegetation has been reported to mitigate the rate of increase in emissions because it acts as a natural carbon sink. This study aimed to mitigate the GHG emissions from energy consumption in Surakarta and formulate recommendations for control. It commenced with calculating the emission factors based on the IPCC formula and determining the key categories using the Level Assessment approach. It also involved computing the vegetation density according to the NDVI values of the interpretation of Sentinel 2A imagery. The estimation results showed that in 2018, the emission loads from the energy consumption in Surakarta reached 1,217,385.05 (tons of CO2e). The key categories of these emissions were electricity consumption, transportation on highways, and the domestic sector, with transportation on highways being the top priority. These loads have exceeded the local carrying capacity because they create an imbalance between emission and natural GHG sequestration by vegetations.

1. Introduction

The concentration of atmospheric greenhouse gases increased by 60% from 290 ppm CO2e at the beginning of the Industrial Revolution (1880) to 430 ppm in 2014. This figure positively correlates with a 0.9°C rise in the earth's temperature that has led to greenhouse effects and climate change (Henderson et al., 2018). In the last three years, the earth has reached the highest temperature and accelerated sea-level rise, submerging several small islands and destroying habitats (NASA GISS, 2016). Climate change also endangers food supply sustainability. HadGEM2 predictions by the International Food Policy Research Institute show that food production in Indonesia is likely to decrease in 2050 (National Geographic, 2018).

Shuai (2017) affirms anthropogenic activity as a major GHG contributor, especially one involving the consumption of fossil fuels. This activity intensifies as people try to compensate population growth while meeting their needs by resource overexploitation and landuse conversion. At some point, anthropocentric perceptions that view nature as a means of satisfaction of needs are widely lived and, according to Keraf 2000), increase the speed of environmental damage.

Surakarta is an area dominantly designated for urban activities. Because it is the home of great variety and intensity of anthropogenic interventions, the risk of GHG emissions is inevitably high. In urban areas, GHG emissions help to form hotspots in the Central Business District (CBD), main intersections, and signal-controlled road segments (Gulia et al., 2014). As an urban area in a developing country, Surakarta potentially faces the biggest GHG problems arising from fossil fuel consumption, particularly in the industrial and transportation sectors (Alyuz and Alp, 2014). Wright (2005) states that in the transportation sector of developing countries, the use of private vehicles raises GHG emissions.

Emissions in Surakarta potentially increase, considering the status of this city as the center of economy and service for the surrounding hinterlands. Due to this status, the intensity of commuters rises considerably. According to the Head of the Department of Transportation, Communication, and Information of Surakarta (personal communication, March 23rd, 2014), a threefold increase in the number of vehicular traffic takes place during the working hours . Sunarto et al. (2016) confirm that emissions are significant in lanes connecting Surakarta to the hinterlands.

Mitigating GHGs must begin with inventory as a complement to ambient monitoring. Inventory is a part of air status monitoring that acts as a foundation in preparing local air quality management (Gulia et al., 2014). Emission inventory will generate data from specific sources in certain periods (Gioli et al., 2015). Also, Shahbazi et al., 2016) claim that compared to ambient monitoring, it provides the basis for modeling through the ability to present data in more detail, including activities, distributions, and potentials of the pursued emission reduction action plan.

Vegetation has been proposed to decelerate the increase in emissions owing to its ability to absorb carbon naturally. Plants can store CO2, the raw material in photosynthesis, in their bodies as biomass content for quite a long time. They also play a crucial role in providing ecological services related to environmental temperature, absorption function, and habitat for living beings (Barrera and Henriques, 2017). The calculation of vegetation density is therefore essential in implementing mitigation measures against the increasing rate of emissions. As for the ability of plants to sequester carbon, it is assessable through vegetation indices obtained from the interpretation results of satellite imagery. An example includes the normalized difference vegetation index (NDVI), which is commonly used to compute or indicate vegetation density in a specified area. From NDVI values, the biomass contained in the vegetation is measurable. Sentinel 2A is a high-resolution satellite image suitable for small study areas. Its spatial resolution is 10 m.

2. The Methods

Research Location and Time

This research took place within the administrative borders of the City of Surakarta, covering an area of 44.04 km2. It was conducted in March-June 2018 by utilizing the data available in 2017-2018.

Instruments and Materials

The research instruments included questionnaire sheets containing emission factors, which were arranged according to the data requirements listed in the IPCC Guidelines (IPCC, 2006), as well as pencils, pens, and laptops equipped with Microsoft Office and the IPCC GHG simulation software. The research materials were secondary government documents on the basic data required for the calculation and the guidelines for emission factor inventory issued by the IPCC and the government.

Data Collection

For the calculation, the basic data were collected using a top-down approach that began with a Focus Group Discussion (FGD) with data shareholders. When the data of emission factors were unavailable, they were completed using credible and accountable external sources, such as the provincial/central data, regional collaborator data, legitimate scientific articles, and expert judgment. Emissions from energy consumption were classified by activities, namely transportation (highways and railways), domestic activity, industry, and electricity consumption. This paper only calculated emissions from the energy consumption category. The vegetation data were interpreted from the Sentinel 2A satellite imagery retrieved on August 27, 2017.

Data Analysis

Emissions were quantitatively estimated using the IPCC standard emission formula:

$$E = AD \times EF$$

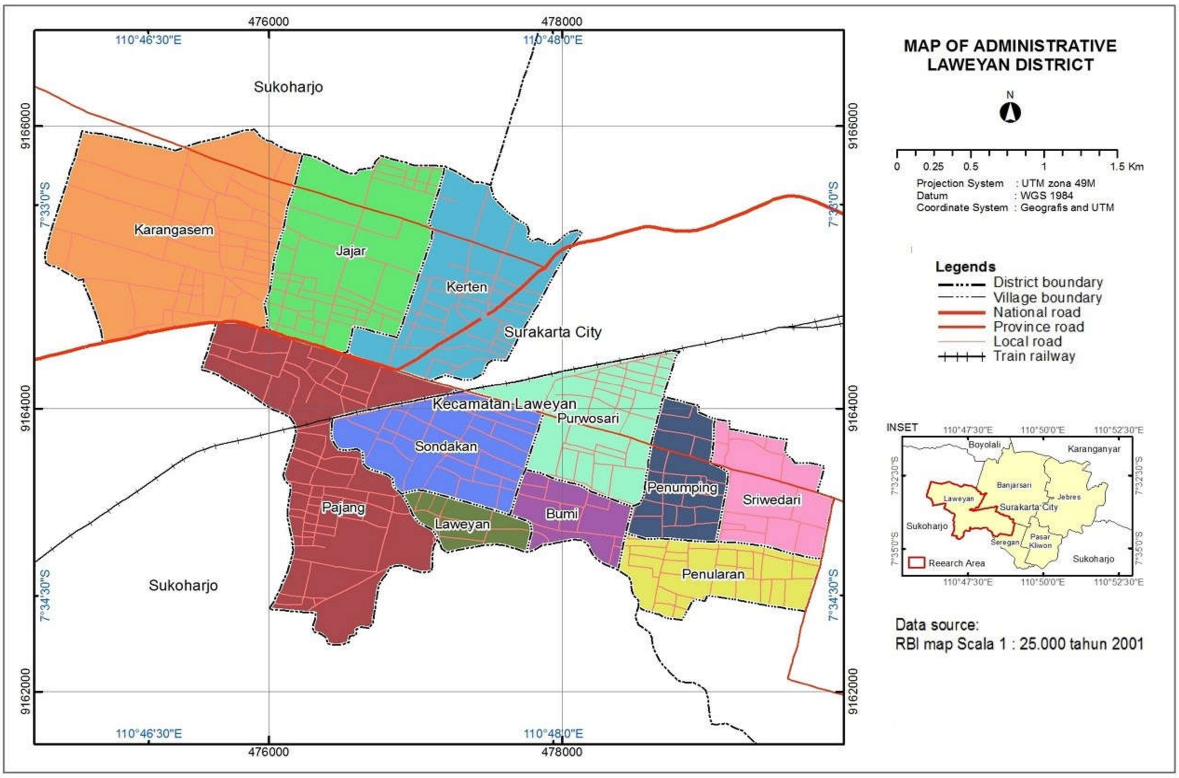

Figure 1. Administrative area of Surakarta City

where
E is total emissions (ton/year),
AD is activity data (the measurement unit depends on the basic data and/or emission factors)
EF is the emission factor.

In this estimation, the activity data was retrieved from the compiled data that had been converted into heat or energy units using net calorific values–expressed in both standard international (SI) and national units. Because Indonesia still has no specific emission factors for all sources inventoried, this research used the emission factors cited in the IPCC document (2006).

The key categories of GHG emissions were computed using the Level Assessment approach.
The equation is as follows.

$$L_{x,t} = |E_{x,t}| / \Sigma |E_{x,t}|$$

where
Lx,t is a ratio of determinants of emission in sector x to total emission t Ex,t is the emission load in sector x to total emission t

Key categories are the main categories or sectoral groups with an emission load up to 95% of the total emissions in an area or the main categories set by the IPCC. GHG from energy utilization was evaluated by the IPCC simulation, that is, processing data of changes over the last six years to calculate the equilibrium of carbon storage and sequestration.

Details on vegetation density were extracted using the NDVI equation below.

$$NDVI=(NIR-Red)/(NIR+Red)$$

where
NDVI = Normalized Difference Vegetation Index, NIR = Near-infrared band in the pixel, R = Red band in the pixel

NDVI ranges from -1 to 1. Positive values indicate high vegetation density, whereas negative ones represent low vegetation density. The results of the NDVI were interpreted visually to determine the classification of the vegetation density. Afterward, measurements in the field were conducted to identify the biomass content using the following Brown's formula. Aside from biomass content, the carbon content was also estimated using Brown's formula (1997), that is, 0.45 times the total biomass.

Based on the available NDVI data in the study area, this research estimated the amount of carbon sequestration using the Gross Primary Project (GPP) approach. The equation below is the standard formula for its calculation.

$$GPP = LUE \times fAPAR \times PAR$$

(Angel and Sheppard, 2005)

GPP = Gross Primary Product (gC/m2/day)
fAPAR = Fraction of Absorbed Photosynthetically Active Radiation (MJ/m2/day)
PAR = Photosynthetically Active Radiation (MJ/m2/day)
LUE = Light-Use Efficiency (gC/MJ) = 1.5 gC/MJ is recommended for the Asian regions (Kurniadi et al., 2016)

GPP factors in the LUE model, which relies on the correlation between NDVI and fAPAR. In most Asian regions, the correlation is mathematically defined as follows.

$$fAPAR = -0.08 + 1.075\ NDVI$$

(Kurniadi et al., 2016)

Apart from fAPAR, GPP also involves the amount of sunlight used by plants for photosynthesis or termed Photosynthetically Active Radiation (PAR). The highest PAR used in this mechanism is estimated to be half of the solar radiation that reaches the Earth's surface (Black, 2006; L.S.S, 2006). Based on this estimate, the amount of PAR is as follows.

$$PAR = 0.5 \times ISR$$

ISR = intensity of solar radiation (MJ/m2/day)

Therefore, the ISR of the City of Surakarta during the time of research (2018) was 633.74 MJ/m2/year. This ISR value was then used in the calculation of GPP.

3. Result and Discussion

Surakarta is topographically a basin area that preconditions Thermal Inversion and, therefore, increases the risk of GHGs accumulating at low altitudes and being trapped in this basin. Because air pollutants and GHGs are substances released from the emission process, their inventory becomes necessary and has been legally confirmed in the Governmental Regulation No. 41 of 1999 as a component of integrated local air quality management. Table 1 below is the GHG inventory in the energy consumption sector in Surakarta.

Estimates of the total GHG emissions from energy use were 1,210,022.64 tonCO2/year, 123.7 tonCH4/year, and 15.37 tonNO2/year or equivalent to 1217695.19 ton of CO2e per year. Two activities are the main contributors to GHGs in Surakarta. The inventory revealed that electricity consumption and transportation on highways emitted the most carbon dioxide (Figure 1). Traffics on highways also generated the most significant amount of methane (CH4) and nitrogen dioxide (NO2). Based on the carbon dioxide equivalents, energy consumption activities that majorly contributes to GHG emissions are electricity consumption (64%), transportation on highways (26%), and non-electricity domestic energy consumption (8%).

Based on the calculation in the Level Assessment approach, the key categories ofGHG emission from energy use in Surakarta are electricity consumption, transportation on highways, and domestic energy consumption. The results showed that these three activities contributed more than 95% of GHGs in the city; therefore, the recommendations need to include their prioritization in the local GHG reduction plan. However, electricity consumption produces emissions because there are currently no power plants within the administrative borders of Surakarta. Accordingly, other locations that have power plants are most likely to feel the direct impact of these emissions. This research then focused only on activities that directly produces emissions, and two key sources were identified, namely transportation on highways and domestic energy use.

Considering that the domestic energy has been entirely converted to LPG–an environmentally friendly fuel, reducing the emissions in this sector becomes insignificant. As a result, transportation on highways is a top priority.

Moreover, the government is deemed powerless to limit the rapidly growing ownerships of motor vehicles as the sources of emission, which supports the decision to prioritize emission reduction in this activity. Apart from this reason, traffic highways are predicted to intensify due to transportation loads coming from other regions and the development of Surakarta as a city for transit and MICE (meeting, incentives, convention, and exhibition).

The intensity of the impact of landuse change in the past five years shows that the natural carrying capacity of carbon sequestration in Surakarta was already exceeded in 2012 (Figure 2). It means that the biogeochemical cycle can no longer accommodate or counteract the GHG emissions, especially carbon dioxide, and instead, they are disposed of to nature as pollutants. The depleting area of vegetation and landuse that have a high carbon absorption ability supports this condition. As seen in Figure 2, the natural carbon stock continued to experience a deficit (loss), while the emissions increased with no to little sequestration. The amount of unabsorbed carbon showed an increasing trend from 2013 to 2016.

Table 1. The GHG inventory in the energy use sector

Categories of activities	Emission parameters (tonnes anually)		
	CO_2	CH_4	NO_2
1.Transportation			
a. Highways	308107	122	15
b. Railways	2414.62	0.13	0.13
Industries	17706.71	1.57	0.24
Domestic	90882.42	7.20	0.14
Trade	8751.61	0.69	0.01
Electricity Consumption	782160.27	0	0
GHG from energy use	1210022,64	123,70	15,37

Source: Primary calculation (2018)

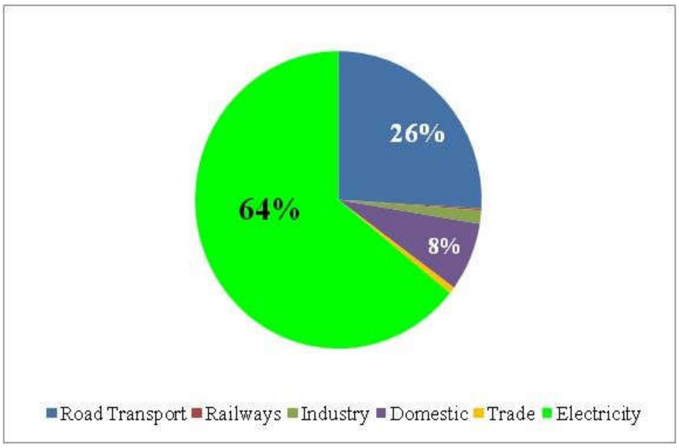

Figure 2. Contribution of activities in the energy use sector to GHG emissions in the City of Surakarta

Indonesia aims to have reduced 29% of its GHG emissions by 2030, as confirmed by its government in the Intended Nationality Determined Contribution (INDC) document during the Conference of the Parties (COP) 21 Paris in December 2015 (Saturi and Nugraha, 2016). In 2018, the Ministry of Environment and Forestry stated that Indonesia had successfully reduced its GHG by 8.7% (Winata, 2018). Emission inventory acts as a media to monitor emission loads while evaluating the plans for emissions control on a regional scale. The inventory in Surakarta showed a different trend from the statement of the Ministry of Environment and Forestry. In the energy use sector alone, emissions increased more significantly than the 2010-2014 inventory. The latest GHGs from energy consumption even exceeded the 2010 projections, which were based on the 2010 inventory (917,782 tons of CO2e/ year).

Laweyan, a district in Surakarta, is close to the city center. The majority of its activities belong to the industrial and trade sectors, and the batik industry is widely known as the main characteristic of this district. Because Laweyan is a Central Business District, the vegetation analysis was conducted in it to create a picture of environmental carrying capacity with regards to carbon sequestration by vegetation. The vegetation density (Figure 3) was defined from the NDVI values resulted from the interpretation of Sentinel 2A satellite imagery.

Based on the NDVI values, high vegetation density only covered 8% of the entire Laweyan District. This condition is mainly because the green open space has been cleared and

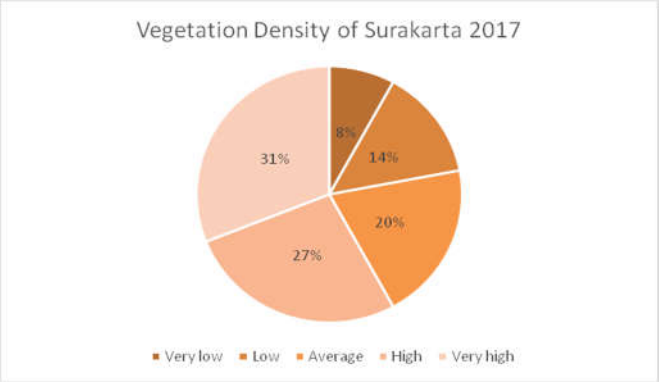

Figure 3. Fluctuations of carbon stocks and sequestrations/ emissions in the City of Surakarta in 2012- 2016

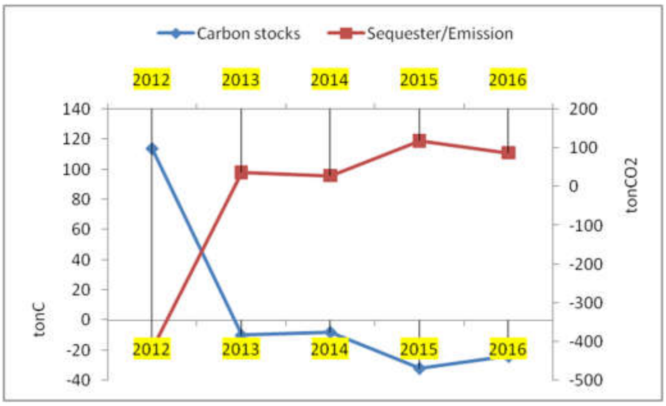

Figure 4. Vegetation Density in Laweyan District

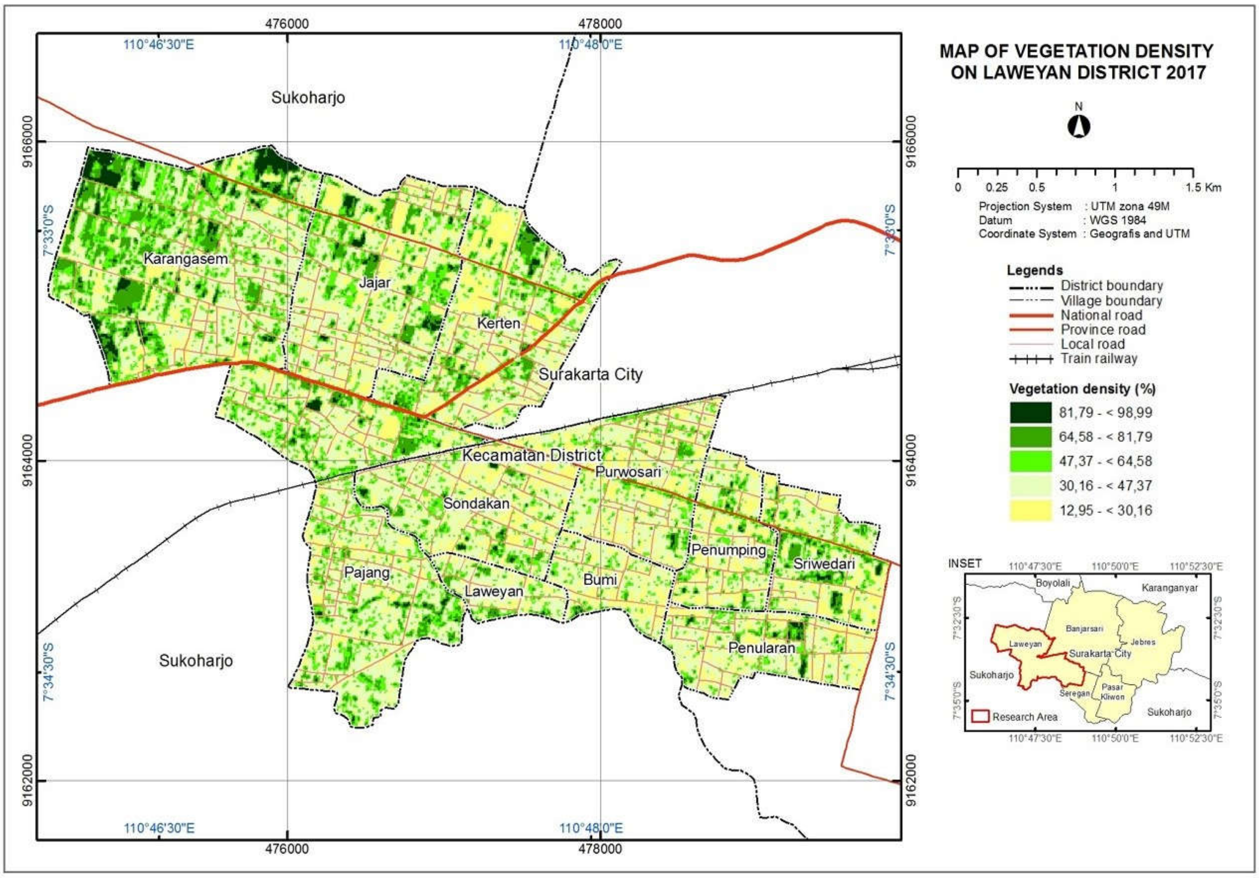

Figure 5. Map of Vegetation Density in Laweyan District in 2017

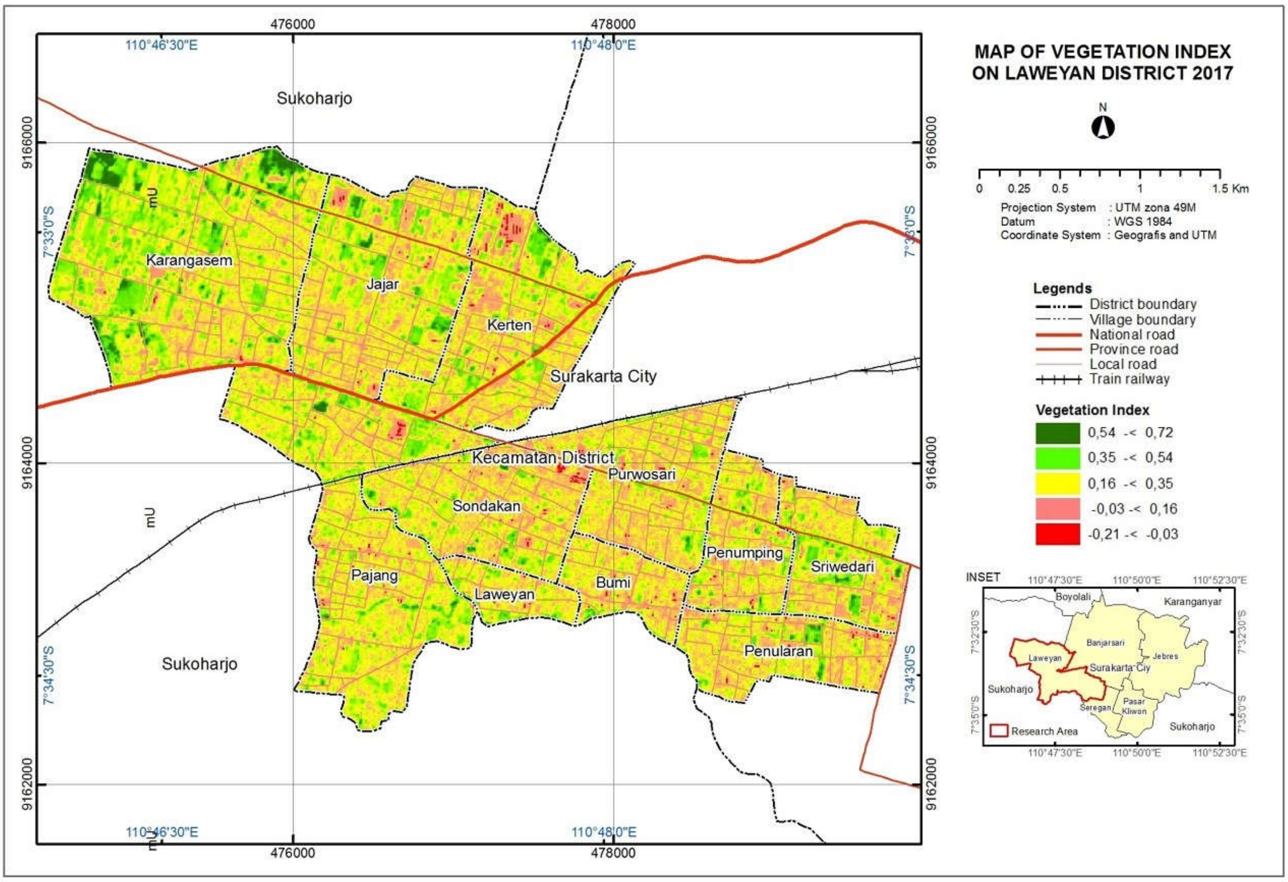

Figure 6. Map of Vegetation Index in Laweyan District, Surakarta, in 2017

spatial interpretation, and environmental factors like air pressure, wind speed and direction, and temperature are negligible, then this finding indicates that the availability of vegetation is not proportional to the needs of air quality control.

The ability of vegetation to sequester carbon in Laweyan District is not proportional to the emissions released by the activities in Surakarta. Among the other districts in this city, Laweyan has the highest vegetation density. In other words, the other districts have relatively smaller carbon absorption ability. The carrying capacity of the environment, especially from the natural function of vegetation as carbon sinks, requires optimization. It is one of the efforts to mitigate or decelerate the increase in emissions in various sectors. Optimization of green open space as a means of vegetation growth needs to be considered.

The calculation revealed that the total biomass was 78597.38 kg, the carbon stock was 39298.45 tons, and the GPP or capability to sequester carbon reached 6487,79 gC/m2/day. The average GPP in each study plot was 216.26 gC/m2/day, and the GPP was unevenly distributed owing to differences in biomass in each plot. This research has proven that tree biomass does not necessarily have a positive correlation with carbon uptake. In some locations, low carbon uptakes were found despite the significant amount of biomass of several small plant species and narrow tree canopies. In this case, GPP can be classified based on dominant vegetation. A group consisting mainly of teak has the most effective GPP, while the mahogany group has the largest GPP (2568.55 gC/m2/day).

Table 2. NDVI values, density, biomass, carbon stock and GPP in each plot

NDVI	Types of vegetation	Coverage	Biomass	Carbon Stock	GPP
		(%)	(kg)	(kg)	(gC/m^2/day)
0.55	Teak	83.06	170.74	85.37	243.00
0.63	Ficus tree	86.19	266.05	133.02	283.88
0.64	Teak	90.84	26.53	13.26	288.99
0.64	Teak	86.11	47.84	23.92	288.99
0.63	Mahogany	85.01	90.60	45.30	283.88
0.6	Teak	82.37	58.70	29.35	268.55
0.63	Teak	85.77	78.76	39.38	283.88
0.68	Mahogany	91.25	209.31	104.66	309.42
0.64	Pterocarpus	88.00	418.41	209.21	288.99
0.38	Pterocarpus	77.54	1890.78	945.39	156.14
0.41	Ficus tree	79.67	2448.88	1224.44	171.47
0.41	Mahogany	79.26	2352.93	1176.47	171.47
0.52	Mahogany	80.69	5524.75	2762.38	227.67
0.51	Mahogany	80.97	1031.59	515.80	222.56
0.59	Mahogany	82.26	3966.83	1983.41	263.44
0.48	Pterocarpus	80.14	3932.25	1966.13	207.23
0.35	Ficus tree	75.88	5274.14	2637.07	140.81
0.35	Ficus tree	66.42	5212.58	2606.29	140.81
0.62	Pterocarpus	84.88	6958.04	3479.02	278.77
0.41	Mahogany	78.04	7634.35	3817.17	171.47
0.27	Mahogany	43.50	2352.93	1176.47	99.93
0.22	Ficus tree	38.35	2391.04	1195.52	74.39
0.31	Teak	53.25	1282.04	641.02	120.37
0.48	Pterocarpus	80.28	2240.84	1120.42	207.23
0.34	Mahogany	68.47	7634.85	3817.17	135.70
0.52	Teak	80.65	1295.21	647.61	227.67
0.53	Mahogany	81.45	3966.83	1983.41	232.78
0.56	Pterocarpus	82.08	3051.92	1525.96	248.11
0.38	Mahogany	76.71	5151.46	2575.73	156.14
0.65	Mahogany	88.50	1636.20	818.10	294.09

Source: primary calculation (2018)

developed into settlements. It is in line with the document "Surakarta in Figures", which claims that settlements occupy 50.46% of the land area (Sari, 2018). The distribution of the vegetation density in Laweyan District in 2017 is presented in Figure 5.

The NDVI ranged between 0.22 and 0.68. The closer it is to 1, the higher the vegetation density. The vegetation in Laweyan District could sequester carbon from 0 to 2.02 tons of CO2 per year. The red color in the NDVI map (Figure 5) marks vegetation with low carbon sequestration ability, whereas the dark green one denotes plants with a high ability to absorb carbon. The 30 observation plots in this study were covered with different types of vegetation and, consequently, produced diverse NDVI values, biomass, and carbon sequestration (Table 2). Based on the regression formula, the biomass in the entire Laweyan District amounted to 9735.62 tons. The carbon sequestration in this district is half of the total biomass, namely 4867.82 tons.

The Vegetation Index Map shows that some vegetation covers were centralized in certain areas. At the center of anthropogenic activities, there was an unequal distribution of vegetation with lower values. If the analysis is solely based on

4.Conclusion

Based on the IPCC formula, the GHG estimates show that the energy use sector in the City of Surakarta emits 1,210,022.64 tons of CO2/year, 123.7 tons of CH4/year, and 15.37 tons of NO2/year, which equal to 1,217,695.19 tons of CO2e per year. The key categories of GHG emissions in this sector are electricity consumption (64%), transportation on highways (24%), and domestic activities (8%). This study recommends that the reduction of GHG emissions from energy consumption needs to prioritize transport activities on highways and take into account the rapid growth of motor vehicles and the less significance of the other two key categories: emissions with electrical generation (electricity consumption) and the optimal energy conversion to an environmentally friendly fuel (LPG) in the domestic sector.

Acknowledgment

Authors would like to express their gratitude to the Government of the City of Surakarta as local environmental stakeholders and the Office of Environment in Surakarta for their assistance in the collection of basic data for emission calculation.

References

Alyuz, U and Alp, K. (2014). Emission Inventory of Primary Air Pollutants in 2010 from Industrial Processes in Turkey, Science of The Total Environment 488-489: 369-381. Retrieved November 15, 2016, from www.elsevier.com/locate/scitotenv.

Angel, S. and S. Sheppard. (2005). The Dynamics of Global Urban Expansion.

Black, S.C.C. (2006). Estimation of Grass Photosynthesis Rates in Mixed Grass Prairie Using Field and Remote Sensing Approaches. University of Saskatchewan Saskatoon.

Barrera, F and Henriques, C. (2017). Vegetation Cover Change in Growing Urban Agglomeration in Chile. Ecological Indicators 8: 265-273.

Gioli, B., Gualtieri, G., Busillo, C., Calastrini, F., Zaldei, A., and P. Toscano. (2015). Improving high- resolution emission inventories with local proxies and urban eddy covariance flux measurement. Atmospheric Environment 115: 246-256.

Gulia, S., Nagendra, S.M.S., Khare, M., and I. Khanna. (2014). Urban Air Quality Management: A Review. Atmospheric Pollution Research 6 (2015): 286-304.

Henderson, R.M., Reinert, S.A., Dekhtyar, P., and A. Migdal. (2018). Climate Change in 2018: Implications for Business. Boston: Harvard Business School Publishing.

IPCC. (2006). Guidelines for National Greenhouse Gas Inventories. Hayama, Japan: Institute for The Global Environmental Strategies.

Keraf, S. (2000). EtikaLingkungan. Jakarta: PenerbitKompas Gramedia.

Kurniadi, K.G., Bayupati, I.P.A., dan I.D.N.N. Putra. (2016). Aplikasi Perhitungan Gross Primary Production dari Data Penginderaan Jauh. Lontar Komputer 7 (1) : 31-39.

L.S.S. (2006). Estimasi Emisi CO2 dari Kebakaran Hutan.

NASA Goddard Institute of Space (GISS). (2016). Global Temperature. Retrieved on January 5, 2019, from climate.nasa.gov/vital-signs/global-temperature.

National Geographic. (2018). Climate Change-5 Way It Will Affect You: How to live with it-Crop Changes. Retrieved on January 5, 2019, from https://www.nationalgeographic.com/climate-change/how-to-live-with-it/crops.html.

Sari C.P., Wiryanto., and Setyono, P. (2018). AplikasiPenginderaanJauhUntukMengkajiTutupanVegetasiKawasan Urban Kota Surakarta 2017 Menggunakan Citra Satelit Sentinel 2A. JurnalPengelolaanSumberDayaAlam Dan Lingkungan9 (1): 152-158.

Saturi, S and I. Nugraha. (2015). Indonesia TargetkanPenurunanEmisikarbon 29% pada 2030.

MongabaySitusBeritaLingkungan on September 2, 2015.

Shahbazi, H., Taghvaee, S., Hosseini, V., and H. Afhsin. (2016). A GIS-based emission inventory development for Tehran. Urban Climate 17 (2016): 216-229.

Shuai, C., Liyin, S., Jiao, L., Wu, Y., and Y. Tan. (2017). Identifying key impact factors on carbon emission: Evidences on panel and time series data of 125 countries from 1999-2011. Applied Energy 187 (2017): 310-325.

Sunarto, Wiryanto, and W. Himawan. (2016). The estimation of emission from the gateways to Surakarta City, Indonesian using the software of Mobilev 3.0 as the basis for an action plan of emission control. Nusantara Bioscience 8 (2).

Winata, D.K. (2018). PenurunanEmisiKarbonTerbaruDihitung. Media Indonesia on September 7, 2018.

Wright, L. (2005). Car-Free Development. Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities Module 3E. Bonn: GTZ Gmbh.