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The Correlation Between Urban Size, Density and CO2, Particulate Matter

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Summary

CO2 emission and air pollution have adverse impact on environment and population. Increasing CO2 emission will increase intensity of extreme weather events such as increase temperature, increase precipitation, sea level rise, flood and droughts. Air pollution also most significant environmental risks to health. It is estimated become major cause of global death from the environmental problem. It is argued that urban areas have significant risk to impact of CO2 emission and air pollution, considering most of global population will live in urban area by 2050.

Urban form plays important roles in determining environmental performances in urban areas, since it affects GHG and air pollution concentration through energy consumption, travel behavior and land use. As element of urban form, urban size and density are considered correlate with environmental performance, for instance, CO2 emission and particular matter. However, how this relationship works still questionable. There is a debatable discussion on which size of city, large or small city, has better energy use and air quality performance. Moreover, the notion about high-density area is better than low-density area still arguable.

This study analyse the correlation between urban size and density and CO2 emission and Particulate Matter in the urban areas cities in England and Wales using statistical analysis method. Overall, population and density are significant variables in influencing CO2 emission and PM. This finding confirms the importance of population and density as element of urban form in determining environmental performances in urban areas. There is a linear relationship between population, density, CO2 and PM. It means large urban areas is not more efficient than small ones. However, comparing result from LAD and urban area, there is no significant difference result. Both of them showing a linear relationship between population, density amd CO2 emission and PM. In addition, the economic condition of urban area influence concentration of CO2 emission.

Keywords

Urban Size, Density, CO2 emission, Particulate Matter

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Abbreviations

IHS	Institute for Housing and Urban Development
CO2	Carbon Dioxide
PM	Particulate Matter
PM 2.5	Particulate Matter 2.5
PM 10	Particulate Matter 10
GHG	Green House Gas
LAD	Local Authority District
MSA	Metropolitan Statistical Area

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Chapter 1: Introduction

1.1 Background

Urban area has an important function, though it only covers about 2 % of total world surface area (Liu, He, et al., 2014). There are 55% of the global population live in urban area and it is projected to increase by 68% in 2050 (UN DESA, 2018). Urban area is also a place of economic activities and engines of economic growth, generating 80% of global Gross Domestic Product (GDP) (UN Habitat, 2016).

Despite its important role, urban area is considered as source of environmental problems, for instance, climate change and air pollution. The increase of global population in urban area and large share of GDP that is generated in urban area will have significant effect on energy consumption and air pollution (UN Habitat, 2016, Fragkias, Lobo, et al., 2013, Chan and Yao, 2008). Urban area consumes 67 – 76 % of world energy use and generate 71 % - 76 % of CO_2 emission (Seto, Dhakal, et al., 2014). Consequently, urban area is recognised as one of the biggest contributor Green House Gas (GHG) emission, because CO_2 is the largest share of the total GHG emission, which is about 78% (Blanco, Gerlagh, et al., 2014). These emissions are mostly related to transportation and energy consumption within city (McCarney, Blanco, et al., 2011) and consider as the primary driver of climate change. Increasing GHG will generates several impacts, one of which is increasing intensity of extreme weather events such as increased temperature, increase precipitation, sea level rise, flood and droughts (Seto, Dhakal, et al., 2014). Moreover, urbanization and development also have environmental impact, for instance, air pollution (UN Habitat, 2016). Air pollution is one of the most significant environmental risk to health. It is estimated become major cause of global death from environmental problem (OECD, 2012). There are some pollutants which belong to air pollution, for instance Nitrogen Oxides (NO_x), Sulphur Dioxide (SO_2), Ozone (O_3), and Particular Matter (PM) (Kampa and Castanas, 2008). According to World Health Organization (2016), PM has significant effect for people compare to other pollutant, also is generally used as indicator of air pollution.

Urban form plays important role in determining environmental performances in urban area, since it affect GHG and air pollution concentration through energy consumption, travel behaviour and land use (Anderson, Kanaroglou, et al., 1996, Newton, 2000, Jabareen, 2006, Milder, 2012). Moreover, a study by Bereitschaft and Debbage (2013) concluded that high-density cities tend to have a lower concentration of air pollutants than low-density cities. Similarly, population density is considered have significant impact in reducing CO2 emission in US and China cities (Lee and Lee, 2014, Fang, Wang, et al., 2015). Therefore, compact development is one of the critical strategies to mitigate GHG emission.

Urban size and density are elements of urban form (Dempsey, Brown, et al., 2010, Schwarz, 2010). They are considered correlate with environmental performance, for instance CO2 emission and particular matter. In the same manner, Dodman (2009b) argued that density as one of the important elements in urban areas regarding impact of climate change. Moreover, Wang, Chen, et al (2016) stated that urban size is important to consider as the basis data to propose recommendation policy regarding urban air pollution problem. In addition, to formulate efficient strategy in order to reduction CO2 emission, urban form is one of the aspects that need to consider in planning process (Wang, Huang, et al., 2018). Han (2014) also stated that good planning of urban form will have a crucial impact in minimize CO2 emission. Therefore, considering significant role of urban size and density as the elements of urban forms, it is important to understand the correlation between urban size and density with environmental performance, for instance, CO2 emission and particular matter.

1.2 Problem Statement

As stated before, urban form is strongly interconnected to environmental impact in urban areas. However, how this relationship works still questionable (Jenks and Jones, 2009, Echenique, Hargreaves, et al., 2012, Milder, 2012, Fragkias, Lobo, et al., 2013)

Regarding urban size, there is a debatable discussion on which size of city, large or small city, has better energy use and air quality performance. Fragkias, Lobo, et al (2013) argued that big cities are not more efficient than small cities. Meanwhile, a study by Oliveira, Andrade Jr, et al (2014) has proven that small cities produces less CO2 emission per capita than larger cities.

Similar with urban size, the notion about high-density area is better than low-density area still arguable. Baur, Thess, et al (2013) argued that population density has a less important role in GHG emission reduction compare to income and household size. Nevertheless, Lohrey and Creutzig (2016) pointed out that high density has a significant impact on air pollution. Implying concentration of air pollution is lower in low-density city than in high-density city.

Although many scholars had conducted about studies about the relationship between urban size and density with CO2 and particulate matter, most of them only analyse between two variables, namely study about relationship between population and CO2 (Oliveira, Andrade Jr, et al., 2014), relationship between population and PM (McCarty and Kaza, 2015), relationship between density and CO2 (Gudipudi, Fluschnik, et al., 2016) and relationship between density and PM (Yuan, Song, et al., 2017). Considering the important role of density from their study, Rybski, Reusser, et al (2017) argued that population and density should be analysed together to reveal the relationship of those variable to CO2.

Therefore, it is essential to conduct a study which analyse the relationship of those variables using statistical analysis to understand the complex relationship among urban size and density with CO2 and particulate matter. Given previous basis, this research aims to contribute to the body of knowledge in this field by investigate them in urban area, using England and Wales as the study location.

1.3 Research Objectives

The main objective of this research is to analyse the correlation between urban size and density and CO2 emission and Particulate Matter in the urban areas in England and Wales.

1.4 Provisional Research Question

The main research question in this study is to what extent does urban size and density correlated with CO2 emission and Particulate Matter in cities within the UK.

1.5 Significance of the Study

In academic perspective, this study will contribute to the scientific knowledge by explaining the relationship between urban size and density correlated with CO2 emission and particulate matter mainly, considering relationship between those variables are still in conclusive. Moreover, this study will enrich scientific knowledge in England and Wales as study location. This study also will contribute to the research on urban form, particularly in urban size and density as one of the urban development aspects to mitigate climate change and adverse the effect from air pollution.

Aside from scientific contribution, this study is expected to enhance the urban environmental spectrum. Urban area will face more challenge in the future due to urbanization and development, particularly environmental issue. Also, considering most of global population will live in urban area by 2050 (UN DESA, 2018). Thus, strategy and policy are needed to address that issue. Consequently, understanding relationship between urban size, density and CO2 and particular matter will give insight in formulating policies by the local government. Result from this study can be utilized as a background information in formulating urban planning policies to achieve environmental sustainability. As stated by Milder (2012), urban form has been recognised in policy document due to its important role in sustainable development.

1.6 Scope and Limitation

The scope of this research focus on the relationship between urban size, density and CO2 and particulate matter. This study only analyses urban size and density as element of urban form. For dependent variables, this limit to only the CO2 emission, instead of all GHG emission. The same treatment goes to Particular Matter (PM) which not include all of the air pollutant. Beside these main variables, Gross Value Added (GVA) as control variable will also be added to seek if that variable affect the model.

This study utilizes secondary existing dataset from reliable sources in one country, United Kingdom, particularly in England and Wales in 2015. Study in single country enable comparison within its cities due to the similar policies by considering its locational geography and similar socio-cultural conditions, compare to the study done in across country.

Unit analysis that has been used in this study is urban area in England and Wales. However, not all of the data is available in urban area unit. Thus, this study applies some assumption to utilise the data. In fact, this is become the main limitation within this study. In addition, this study only covers statistical analysis using secondary data, excluding the spatial analysis coverage by using map.

Chapter 2: Literature Review / Theory

2.1 Urban Size and Density

Urban form refers to physical and non-physical characteristic of urban area. Anderson, Kanaroglou, et al., (1996) defined urban form as spatial arrangement of metropolitan area, include land use and infrastructure pattern. Similar to that, Huang, Lu, et al (2007) refer urban form as spatial characteristic of urban area. They analyse urban form using satellite images of land use. However, urban form not only associated with physical characteristic but also nonphysical characteristic including size, density, shape, scale and land use (Dempsey, Brown, et al., 2010, Schwarz, 2010). Many scholar analyse urban size and density as element of urban form, considering the importance of these variables (Anderson, Kanaroglou, et al., 1996, Milder, 2012, Baur, Thess, et al., 2013, Mohajeri, Gudmundsson, et al., 2015, Legras and Cavailhes, 2016, Fujii, Iwata, et al., 2017, Wang, Liu, et al., 2017, Rybski, Reusser, et al., 2017). Thus, the main discussion in this study will be focusing on urban size and density as element of urban form.

The link between urban form and environmental performance has attracted attention from scholars over the years. Urban form affect greenhouse gas emission emission and air pollution concentration through energy consumption, travel behaviour and land use (Anderson, Kanaroglou, et al., 1996, Newton, 2000, Jabareen, 2006, Milder, 2012). Study by Bereitschaft and Debbage (2013) concluded that high-density city tend to have lower concentration of air polluntants than low-density city. Similar with that Fang, Wang, et al. (2015) found out that urban with compact development leads to reduction of CO2 emission in 30 Chinese cities. However, some researcher found that urban form has modest impact on environmental perfomances. Mindali, Raveh, et al (2004) analysed correlation between urban density and energy consumption, and showed that there was no correlation between them. Research by Baur, Thess et al (2013) also found that density as element of urban form has less important role in GHG emission reduction compare socioeconomic variable. Due to the debate, this study will analyse correlation between urban size and density as element of urban form and environmental perfomance.

2.1.1 Urban Size

Urban size related to economies of scale and productivity (Bettencourt, Lobo, et al., 2007). Agglomeration of people and economic activities in one area could reduce energy use and level of pollution (Bo and Jianfeng, 2015). Large cities are considered have more benefit than small cities. A large city produces more innovation, high density of educational institution and considered more prosperous (Batty, 2011). Provision infrastructure and energy consumption in large cities are more efficient than in small ones, thus lead to minimize CO2 emissions released (Fragkias, Lobo, et al., 2013, Dodman, 2009a, Glaeser and Kahn, 2008, Bettencourt, Lobo, et al., 2007). Oliveira, Andrade Jr, et al (2014) also argued that large cities have maximum advantage related to human productivity and quality of life. However, regarding environmental issues, recent research found that small and medium cities have more benefit than large cities regarding CO2 emissions (Louf and Barthelemy, 2014b). Thus, economies of scale of city in terms of environment is inconclusive.

The importance of urban size in understanding dynamic in cities has already been discuss by many scholars. Urban size is used to understand the impact of urbanization, forecast future condition as result from urbanization also to plan as response from urbanization towards sustainability (Bettencourt, Lobo, et al., 2007). Moreover, Han, Zhou, et al (2016) analysed urban size to get insight about optimal city size regarding air quality. Furthermore, urban size can be used as basis data and information to formulate recommendation policy regarding urban environmental problem to achieve sustainable development (Fragkias, Lobo, et al., 2013, Wang, Chen, et al., 2016). Then, analyse urban size has significant value to understand urban phenomena and to draft policy and recommendation as part of planning process toward sustainability.

Urban size can be analyse based on population size, economic size and land use size (Li, Lei, et al., 2018). However, population size is the most common variable which have been used by scholars in their study (Bettencourt, Lobo, et al., 2007, Fragkias, Lobo, et al., 2013, Oliveira, Andrade Jr, et al., 2014, Louf and Barthelemy, 2014b, Mohajeri, Gudmundsson, et al., 2015, Rybski, Reusser, et al., 2017). Population size is generally defined a number of populations in urban area. Population has important role as determinant and consequence of socio-economic activity in urban area (Fragkias, Lobo, et al., 2013). It is considered as a main driver of urbanization and economic development in urban area. By 2050, urban population is expected to 68% of global population (UN DESA, 2018). The growing urban population together with economic development in the future will have significant impact to environment (Martine, 2009).

Scaling has become interesting subject to study in recent years, particularly in urban area. It enables scholar to analyse correlation between urban size and urban properties for instance infrastructure, GDP and innovation (Bettencourt, Lobo, et al., 2007, Lobo, Bettencourt, et al., 2013). Moreover, scholars can quantify how urban variable change based on population in urban system using scaling. (Bettencourt, Lobo, et al., 2007, Cottineau, Hatna, et al., 2017, Depersin and Barthelemy, 2018).

There are three categories to explain relationship in scaling. Those categories are determined by magnitude of β (scaling exponent), which reflect magnitude of urban property change based on urban size (Bettencourt, Lobo, et al., 2007). First, sublinear scaling ($\beta < 1$) commonly related to economies of scale in terms of infrastructure provision, means doubling the population (increase urban size) will need quantity of urban properties less than double. Therefore, reduced usage of energy and material and reduced concentration of emission and pollution as well. Second, linear scaling ($\beta = 1$) commonly related to basic human needs, means when doubling the population will increase quantity of urban properties as proportionally as increasing urban size. Third, super linear scaling ($\beta > 1$) commonly related to socio economic aspect, means doubling the population will increase quantity of socio economic aspect more than doubling urban size. Superlinear scaling is associated with highest level of productivity. However, super linear scaling also has negative value in terms of pollution, environmental perfomance, number of crime and disease (West, 2017). Activities of population in big cities will increase pollution in the atmosphere, led to low level of environmental perfomance. In summary, big cities have more advantage regarding infrastructure provision and social economic aspect than small ones. It is more efficient to build infrastructure in big cities regarding usage of energy and material. At same time, big cities also have some disadvantage regarding pollution, environmental perfomance, disease and crime. Big cities emit more pollution which result poor environmental perfomance.

As mentioned before, scaling is an important tool to analyse relationship between urban property and urban size in order to understand urban system. Urban development and agglomeration will have significant effect to environmental perfomances. Moreover, CO2 and particulate matter are important aspect which illustrate environmental perfomance in urban area. Using scaling relation in this study will reveal how much population influence CO2 and particulate matter. The result will give insight how urban size and density strategy can be used to reduce emission and particulate matter towards urban sustainability.

2.1.2 Density

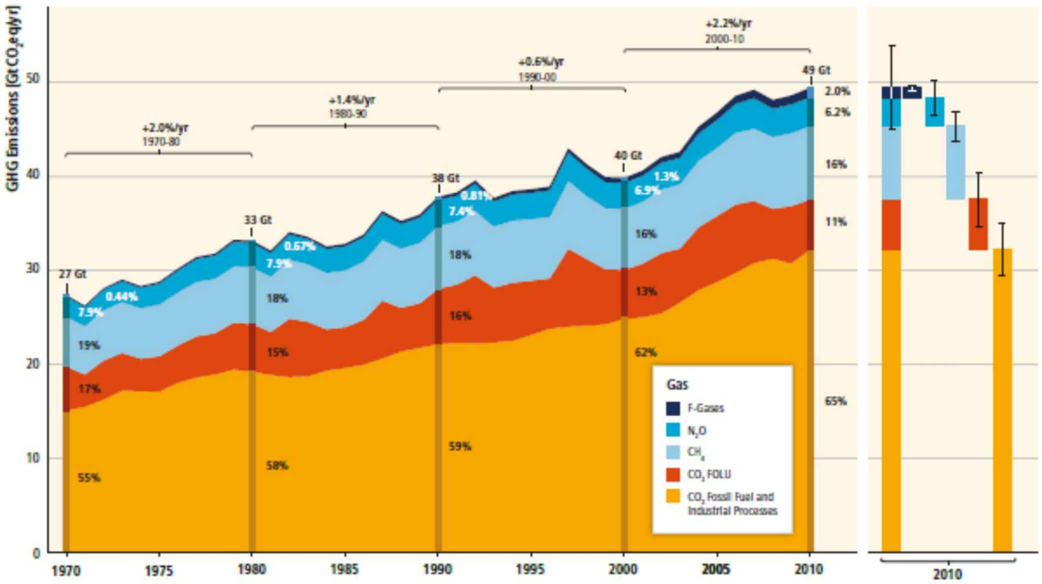
"Density is a key concept in planning, architecture and urban design, as it helps to describe, predict and control the use of land" (Boyko and Cooper, 2011, p.2). Density is used as foundation in planning related to energy efficiency and sustainable development. Compact city is one of examples of urban planning based on density in urban context (Churchman, 1999). In general, compact city is characterized by high residential densities, mixed land use area and short travel distance (Churchman, 1999, Neuman, 2005, Jenks and Jones, 2009). It is argued that compact cities have environmental benefit (Jenks and Jones, 2009) as its objectives are reduce mobility by located different function (residential, service, school) in one area and promotes alternative mode of travel for instance public transportation, walking and bicycling in order to reduce usage of private vehicle (Mindali, Raveh, et al., 2004), further reduce energy usage and lower emission. Characteristic of compact cities enable people to walk and cycle also use public transportation due to close proximity among facilities (Marshall, 2008, Poumanyvong and Kaneko, 2010). Compact cities also offer economies of scale for public infrastructure which will result better environmental performance (Sadorsky, 2014). Provision of public infrastructures for instance road, sewage system, water system and electricity are more efficient in compact cities than dispersed ones, where proximity enable maximum use of resource and reduce cost. Optimize resource and energy use led to reduction of emission and air pollution. However, some scholars argue that compact cities will give negative impact to environment. Intensification development reduce available land for green space (Churchman, 1999). Consequently, influence urban air quality, increase temperature and increase Urban Heat Island effects (Lo, 2016, Dodman, 2009b). This dispute about density increased attention of scholars to study about relationship between density and environment.

There are many ways to measure density, for instance building density, street density and population density (Churchman, 1999). Among the others, population density is common indicator used by scholars (Jabareen, 2006, Dodman, 2009b, Gudipudi, Fluschnik, et al., 2016). Population density generally refer to ratio of person to land area. It is used to measure dimension of compactness (Huang, Lu, et al., 2007, Lee and Lee, 2014). Population density is considered as an indicator in analysing urban environment. Population density influence travelling distance of vehicle, led to reduction of CO2 and Particulate Matter (Gaigné, Riou, et al., 2012, Yuan, Song, et al., 2017). Study by Yuan, Song, et al (2017) analysed urban form and air pollution in China. The result shown that higher densities reduce travelling distance and dependence of vehicle, further reduce CO2 emission . Gudipudi, Fluschnik, et al (2016) also argued that population density influence GHG emission through energy consumption in cities. This study suggested that compact development in new cities and brown development in mature cities are needed in urban development policy in order to reduce carbon footprint.

2.2 CO2 Emission

According to Cubasch, Wuebbles et al (2013), Green House Gas (GHG) emission is one of the indicator and significant drivers for climate change. In past 10 years, amount of GHG emission increase significantly compare in the previous three decades (Edenhofer O., Pichs-Madruga, et al., 2014). The main driver behind the increasing of GHG emission are consumption, international trade, population growth, economy growth, and energy consumption (Blanco, Gerlagh, et al., 2014). Increasing GHG emission have impact in increasing intensity of extreme weather events such as increase temperature, increase precipitation, sea level rise, flood and droughts (Seto, Dhakal, et al., 2014). Related to this, urban population will face the higher risk compare others because two third of global population will live in urban area by 2050 (UN DESA, 2018). Overall, increasing concentration of GHG emission have significant impact on urban area. Therefore, reducing GHG emission is needed to minimise impact of climate change.

Figure 1: Number of GHG Emissions by Gases Between 1970 and 2010



Source : (Edenhofer O., Pichs-Madruga, et al., 2014)

CO2 is the most dominant GHG compare the others, for instance methane (CH4), Nitrus Oxide (N2O), and CFC. Data collected on GHG emission over the past 40 years clearly show CO2 as the largest component. Concentration of CO2 in global world has recorded the greatest increased by 90%, compared with CH4 and N2O which are only increase by 47% and 43% respectively (Blanco, Gerlagh, et al., 2014). Moreover, figure 1 show that CO2 has the largest share of GHG emission from 1997 – 2010. In 2010, share of CO2 emission is 76 % of total global GHG emission, while CH4, N2O and fluorinated gases only accounted by 16%, 6,2 % and 2 % respectively (Edenhofer O., Pichs-Madruga, et al., 2014). Urban area is considered as one of the most contributor of CO2 emission. According to Seto, Dhakal, et al (2014), urban area consumes 67 – 76 % of world energy use and generate 71 % - 76 % of CO_2 emission. As CO2 is the major component of GHG, it is important to reduce CO2 emission in order to reduce GHG emission and minimise its impact, particularly in urban area.

2.3 Particulate Matter

Air pollution is one of the most significant environmental risk to health. It affects human health, for instance, cardiovascular and pulmonary disease (Bereitschaft and Debbage, 2013). Moreover, air pollution is estimated become major cause of global death from environmental problem (OECD, 2012). Data from World Health Organization (2006) showed that air pollution cause more than 2 million people death early annually. In addition, air pollution is used as indicator of sustainable development, it reflects in one of Sustainable Development Goals (SDGs) which is SDG 11 about sustainable cities and communities (World Health Organization, 2016). Thus, air pollution is important aspect to analyse to achieve sustainability.

Air pollution sometimes is associated with poor air quality. Urban area usually has poor air quality due to high pollutant which is generated by economic activities and road traffic (Meijer, 2012). Thus, impact of air pollution in urban areas will more significant compare to rural areas. Meijer (2012) also argued that population density in urban area make impact of air pollution more significant. Increasing trend of population worsen problem of air pollution. Based on that, future growing population in urban area is vulnerable to exposure of air pollution.

Air pollution can be distinguished into two categories, based on source of the pollution, which are indoor air pollution and outdoor air pollution (Farmer, Nelin, et al., 2014). Indoor air pollution can be described as polluted air within building. Major sources of indoor air pollution are from building material and household fuel combustion (Farmer, Nelin, et al., 2014, Meijer, 2012). Different from indoor air pollution, outdoor air pollution can be described polluted air outside building. Major sources of outdoor air pollution are combustion gases from motor vehicles and industrial processes (Farmer, Nelin, et al., 2014, Meijer, 2012). It is important to analyse about outdoor air pollution because outdoor air pollution is major cause for rising trend in population morbidity and mortality (Wu, Wang, et al., 2016). As World Health Organization (2016) stated that outdoor air pollution lead to cardiovascular disease and death. Furthermore, outdoor air pollution also can influence indoor air pollution in building through incoming air by ventilation (Meijer, 2012).

Particular Matter (PM) is generally used as indicator of air pollution. It is argued that PM have significant effect on human health compare to other pollutant, for instance Nitrogen Oxides (NO_x), Sulphur Dioxide (SO_2), and Ozone (O_3) (World Health Organization, 2016). Exposure to PM is associated with respiratory problem and significant mortality (Srimuruganandam and Nagendra, 2010). At global scale, exposure to PM cause 3% of cardiovascular and respiratory problem and 5% of mortality from lung cancer (WHO, 2013). PM categorized into two based on their size which are PM10 with particles smaller than 10 µm (coarse PM), PM2.5 with particles smaller than 2.5 µm fine particles (fine PM) (World Health Organization, 2006). Both of them are considered cause health effect in urban because their adverse effect to health. PM10 can penetrate into upper lungs, while PM 2,5 can reach inside lung and enter blood system (World Health Organization, 2016, Kampa and Castanas, 2008, World Health Organization, 2006). PM considered as indicator for health effect of air pollution. Therefore, it is important to reduce PM concentration to minimize its impact.

2.4 Relationship Between Variables

In the previous section, a detail description of the main concepts has been explained. This section will further explain on the relationship between variables.

2.4.1 Relationship Between Urban Size, density and CO2 Emission

It is argued that increasing CO2 emission basically effect of human activity, particularly in urban area (Solomon, Qin, et al., 2007). Energy is used to support human activities, which emit CO2 emission. People use energy in provision of infrastructure, mobility, production activities and residential (Wang, 2014). Economic growth due to agglomeration economy and population growth need higher demand for energy usage, leads to increasing CO2 emission. Zhao and Zhang (2018) analysed influence of urbanization on energy consumption in China for 30 years. They found out that the growth of urban population significantly influenced energy consumption. Increasing 1% of urban population in China, lead to increasing energy consumption by 1.4 % during 1980 – 2010. Moreover, density also has significant impact on energy consumption. Study by Karathodorou, Graham, et al., (2010) analysed urban density and fuel consumption in 100 cities across country. The result shown that 1% increase in urban density is associated with lower fuel consumption by 0.33 %, meaning density affects energy consumption. High density is considered more efficient in energy use. High density area promote shorter travel distance for household to do their activities, consequently, lower fuel consumption (Karathodorou, Graham, et al., 2010, Su, 2011). Overall, human activities influence CO2 emission in urban area through energy consumption.

The relationship between urban size and CO2 emission; and between density and CO2 emission has been extensively investigated. Previous studies which analysed the relationship between population and CO2 emission, showing conflicting result on whether large cities are more efficient in terms of CO_2 emission compare to small cities. Fragkias, Lobo, et al (2013) analysed the relationship between urban size and CO_2 in the USA metropolitan areas through scaling analysis. The result shown that there is almost linear relationship between population and CO_2 emission. It means that the large urban areas are not more efficient than the small ones in terms of CO_2 per capita. Similarly, Mohajeri, Gudmundsson, et al (2015) examined correlation between urban size and CO_2 emission. They found linear relation between variables. Recent studies by Wang, Madden, et al (2017) explored three elements of urban form which are population, compactness, and polycentricity with CO_2 emission at the city level in China. The result shown that there is a sub-linear relationship between population and CO_2, means that there is economic of scale in city in terms of CO_2 emission per capita. Moreover, this study also highlights that population is one of the important variables in determining CO_2 efficiency compare to others spatial variables. On the other hand, research by Louf and Barthelemy (2014b) shown that population has super linear relationship with congestion. It demonstrated the large population cities have more concentration of CO_2 emission as a consequence of congestion than the city with small population. Similarly, Oliviera, Andrade Jr, et al (2014) pointed out that there is super linear relationship between population and CO_2 emission in the US implying, small cities are more environmentally friendly than large cities. In addition, using data from 256 across country, Rybski, Reusser et al (2017) found the difference relationship between CO_2 emission and urban size, depend on the economic condition of countries. Cities in developed countries shown sub-linear relation, while city in developing countries shown super-linear relation. It means that large cities in developed country tend to be more efficient in terms of CO_2 emission compare to small cities.

As mentioned before, compact cities are considered one of effective strategies to reduce energy consumption and emission. In empirical study, notion about compact city still arguable. Some scholar argued that high density cities reduce CO_2 emission, while others not. Lee and Lee (2014) in their study found different result about population density and CO_2 emission. They analyse relationship between population density and household CO_2 in 125 urban areas in US. The result shown that population density influence the reduction of CO_2 emission. Similar with that Gudipudi, Fluschnik, et al (2016) analyse correlation between density and CO_2 emission in US by applying City Clustering Algorithm (CCA) and utilizing CO_2 emission data from Vulcan Project. The study presented that population density influenced CO_2 emission in city, means higher population density will lead to lower CO_2 emission. On the other hand, Mindali, Raveh, et al (2004) revealed negative correlation between urban density and energy consumption. Similarly, Baur, Thess, et al (2013) analysed the relationship between population density and GHG emissions in Europe. The result shown that population density has less important role compare to income and household size in GHG emission reduction.

In summary, relationship between urban size and density with CO_2 emission still debatable. Some scholars argued that urban size and density have significant effect to CO_2 emission (Fragkias, Lobo, et al., 2013, Lee and Lee, 2014, Gudipudi, Fluschnik, et al., 2016, Wang, Madden, et al., 2017). Meanwhile others scholars argued that urban size and density are not significant influencing concentration of CO_2 emission (Baur, Thess, et al., 2013, Louf and Barthelemy, 2014b, Oliveira, Andrade Jr, et al., 2014).

2.4.2 Relationship Between Urban Size, Density, and Particulate Matter

Human activity in urban area contribute to increasing concentration of PM. PM is released in the atmosphere by motor vehicle, industrial activity, construction activity, incinerator and natural dust (Kampa and Castanas, 2008). It is argued that the major source for PM is from combustion fossil fuel. Globally, 25 % of PM 2.5 and PM 10 was contributed by traffic (Karagulian, Belis, et al., 2015). Urban development is related to mobility. Then, population and economic growth in urban area will increase demand to travel and further increase concentration of PM (Karagulian, Belis, et al., 2015). Therefore, it will exacerbate impact of PM on human.

A number of studies have been explored the relationship between urban size and particulate matter; and between density and particulate matter. Regarding to urban size, McCarty and Kaza (2015) found out that population is significantly correlated with PM 2.5 in US. Increases number of people result in increases concentration of PM 2.5. At global scale, Han, Zhou, et al (2016) analysed the scaling relationship between population and PM2.5 concentration. They also found that urban population influence concentration of PM 2.5. Although the influence is different across countries. In large cities in Asia and Africa, population have shown significant influence on PM2.5 concentration. Meanwhile, urban population in large cities in North America and Europe influence small increase in concentration of PM 2.5. However, some scholars argued that there is no correlation between population and PM. Using data from 157 Chinese cities, Yuan, Song, et al (2017) did not find correlation between population and PM. Pollutant. Similarly, Liu, Arp, et al (2017) also found insignificant relationship between population and PM.

The environmental impacts of density are still a debateable issue. Some researcher found that density associated with lower concentration of air pollution, while others not. Bereitschaft and Debbage (2013), explored relationship urban form and air quality. This study found that population density significantly correlated with higher PM2.5 concentration. Similarly, Kashem, Irawan, et al (2014) found that cities with high density have lower concentration of PM 2.5 compare to cities with low density. Recently, Lohrey and Creutzig (2016) analysed relationship urban density and air pollution. Result from this study revealed that high density has a significant impact on air pollution. This means concentration of air pollution is lower in low density city than in high density city. Recent studies has approved that increase in population density is associated with a significant decrease in the concentration of PM 2.5 and PM 10. Meanwhile, some studies found density have not significant impact on PM. Study by Rodriguez, Dupont-Courtade, et al (2016) showed that the relationship between density and PM is not significant. Similarly, Fan, Tian, et al (2018) also found that there is no correlation between density and PM.

These studies have different conclusion about the impact between urban size and density on PM. While some researchers have found significant relationship between urban size and density on PM (Bereitschaft and Debbage, 2013, Kashem, Irawan, et al., 2014, McCarty and Kaza, 2015, Han, Zhou, et al., 2016, Lohrey and Creutzig, 2016, Yuan, Song, et al., 2017). There are others who did not find any significant relationship between Meanwhile others scholars argued that urban size and density are not significant influencing concentration of PM (Rodríguez, Dupont-Courtade, et al., 2016, Yuan, Song, et al., 2017, Liu, Arp, et al., 2017, Fan, Tian, et al., 2018)

2.5 Urban Area

In the scientific knowledge realm, there is no singular definition about urban. The definition varies, depend on how a country determine their urban area. Heterogeneity definition of urban area across countries can be found on the UN publication in 2014 about urbanization, for instance on the definition of urban area in Norway is the localities with minimum 2000 inhabitants, meanwhile in Netherlands, it is the municipalities with at least 20.0000 inhabitant (Desa, 2014). Population is not the only characteristic to formulate criteria in defining urban. The characteristic for determining urban area is vary from population, population density, percentage of job in non-agricultural sector and the availability of infrastructure (Desa, 2014). Moreover, boundary is also an important aspect to define urban area. Countries mostly use administrative boundaries to define urban area in their country, for example municipalities, localities, cities, towns and district (Montgomery, Stren, et al., 2004, Desa, 2014).

There are several approaches used to delineate boundary of urban area. These approaches employ three general boundaries; administrative, functional and morphological boundaries (Seto, Dhakal, et al., 2014). Administrative boundaries are the most common boundaries of urban area; it refers to political boundaries of urban. There are many urban data available using this boundary, because mainly national statistics produce data based on the formal administrative boundary (Antikainen, 2005). However, some scholars argued that urban data using this boundary have some limitation. Administrative boundaries do not illustrate the development of urban area. Sometimes the boundary involves not only the urban area but also surrounding rural countryside, and bundled them together into single administrative area (Antikainen, 2005).Moreover, due to fix boundary and small possibility of changing boundary frequently, administrative boundary cannot accommodate urban development (Pumain, 2004). Regardless the limitation of administrative boundaries, this method still used by scholars in their research. Mereilles, Neto, et al (2018) analyse the scaling exponent between urban size and urban variables, for instance infrastructure and accessibility of basic services. Municipalities in Brazil define urban based on administrative boundary including rural characteristic in their criteria. Due to sensitivity urban boundary in scaling analysis, the researcher eliminates rural area by adding minimum density cut-off as additional criteria.

In the literature, functional boundaries also used to define urban area. Defining urban area using functional boundaries enable the scholar to depict urban socio-economic characteristic such as economic activity and commuting zone (Seto, Dhakal, et al., 2014). This method allows the scholar to do comparison analysis of urban properties beyond rigid boundary such as administrative boundary. Moreover, this method is able to can illustrate the linkage between economic and spatial data in polycentric urban. Urban area can have one or more urban centre that intertwined. Due to focus of this method based on functional activities, it can linked together separate urban centre in single boundary (Brezzi, Piacentini, et al., 2012). Metropolitan Statistical Area (MSA) in US is one of the examples of urban area which is define based on functional approach. MSA consist of core area is an area with minimum 50.000 inhabitant and have integration economy with core area (US Census Bureau, 2016). Fragkias, Lobo, et al (2013) use this urban definition to study about relationship between urban size and CO_2 in US.

Another way to define urban area is based on morphological boundaries. This approach allows the scholar delineate to delineate urban area based on built environment, land use and land cover using maps or spatial image (Seto, Dhakal, et al., 2014). Some scholars argue that delineating urban area based on this approach may enable them to reflect urban as continuous built up area beyond strict delineation (Pumain, 2004). However, the availability of urban data in this boundary is not widely available yet, thus it is a bit challenging to be utilized. National statistic mostly still use administrative boundary as their unit analysis, but then the data sometimes is not coincide with morphological boundary (Pumain, 2004).

There are some issues regarding various way in defining urban. Measurement of urban data is depend on how urban is defined in each country. It will become an issue to compare urban data across regional studies, due to variation of urban definition (Humeres and Samaniego, 2017). For instance, measuring concentration of CO_2 emission is depend on urban boundary. There are many studies about urban GHG emission use different urban definition (Marcotullio, Sarzynski, et al., 2013). Some scholars analyse urban GHG based on administrative boundaries of municipality, others use county. Therefore, comparing urban CO_2 emission across regional studies is challenging. Furthermore, heterogeneity definition of urban area become an issue in scaling analysis (Arcaute, Youn, et al., 2013, Louf and Barthelemy, 2014a). How urban is define really influence scaling exponent, consequently can led to misleading conclusion.

Despite of different approach on how to define urban area, there is no consensus to determine which the best approach to define urban area is. Each of the approach can be used depend on the purpose of study. Moreover, there is no rule that scholar only can choose one method to define urban, it can be combination among them. For instance, Potts (2017) use multicriteria and method to define urban in her study to analyse urbanization data of Kenya.

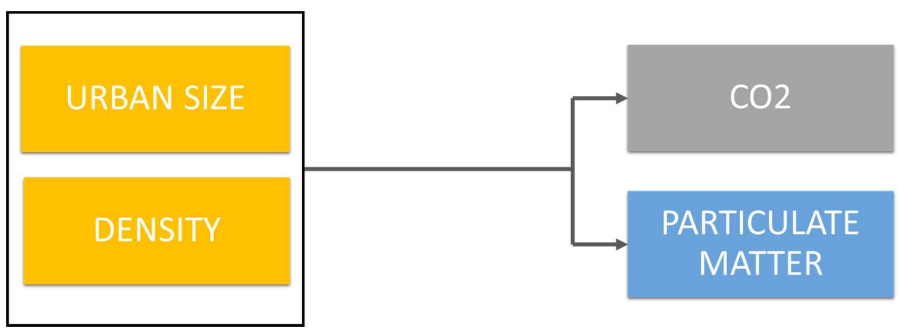
UK has its definition of urban area. Recently, Office for National Statistic UK published new approach to define urban through Major Town and Cities statistical geography in England and Wales. Major town and cities are classified based on population size and area of built environment. This definition use built-up area boundary to classify major town and cities. Built-up area where residential and/or workday population more than 75.000 people are categorised as major town and cities (Office for National Statistics, 2017a). Due to comprehensiveness of urban definition, this study will use that definition to define urban area.

2.6 Conceptual Framework

Main concept in this study has been explained in the previous section. This study aims to analyse correlation between urban size and density as elements of urban form with CO2 and particulate matter. According to literature, urban size and density plays an important role as variable of urban form in determining CO2 emission and concentration of Particulate Matter. In addition growing population could not be separate with economic growth. Therefore, GVA which illustrate economic condition of cities is added as control variable.

In this conceptual framework, two variables are considered as the dependent variables namely CO2 (y_1) and particulate matter (y_2) and two variables are considered as the independent variables which are urban size (x_1) and density (x_2). There are two independent regression analysis will be used as a tool to analyse correlation between the concepts, which will explain further in next chapter.

Figure 2: Conceptual Framework



Source: Author, 2018

Chapter 3: Research Design and Methods

In this chapter, the operationalization and research design to answer the research question are discussed. This chapter also explain data collection method and data analysis also validity and reliability of this research.

3.1 Research Question

The main research question is to what extent does urban size and density correlated with CO_2 emission and Particulate Matter in cities within the UK

3.2 Operationalization: Variables and Indicators

The concepts presented in previous chapter are operationalized in this section. All the terms have been explained in the literature review from various scholars. These concepts, variables, and indicator were contextualized from literature. Table 1 below show independent and dependent variables followed by definition and indicator which will used in this research

Table 1: Operationalization Variables

Dependent/ Independent	Concept	Variable	Definition	Indicator	Data Year	Source
Independent	Urban Size	Population	Resident of city	Number of Resident	2015	(Office for National Statistics, 2017b)
Independent	Density	Population Density	Ratio of person to land area (Office for National Statistics, 2017b)	Number of Population Density (Person/Square Kilometers	2015	(Office for National Statistics, 2017b)
Dependent	CO2 Emission	CO2	"A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas, and coal, of burning biomass, of land use changes (LUC) and of industrial processes (e.g., cement production)" (Allwood J.M., Bosetti, et al., 2014 p.1254)	Total CO2 per year (tCO2)	2015	(Department for Business, Energy and Industrial Strategy, 2017)
Dependent	Particulate Matter	PM 2.5	a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air with particles smaller than 2.5 µm fine particles (UK's National Atmospheric Emissions Inventory, 2017a)	tonnes	2015	(UK's National Atmospheric Emissions Inventory, 2017a)
		PM 10	a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air with particles smaller than 10 µm fine particles (UK's National Atmospheric Emissions Inventory, 2017b)	tonnes	2015	(UK's National Atmospheric Emissions Inventory, 2017b)
Control Variable	Gross Value Added	Gross Value Added	GVA is GDP excluding taxes and subsidies on products at regional/local level (Harari, 2016, p.4)	£ million	2015	(Harari, 2016)

Source: Author (2018)

3.3 Research Strategy

Research strategy which will be used in this study is desk research using secondary quantitative data. Desk research is the most efficient and most effective research strategy considering this study will use secondary statistical data with large number of observations (Van Thiel, 2014). This study will use existing database from United Kingdom Government. Therefore, Desk research is the most appropriate strategy, because this strategy is used when existing data is already available (Van Thiel, 2014)

3.4 Data Collection Methods, Sample Size and Selection

The secondary quantitative data used in this study is collected from different data sources. Independent variables data are obtained from the Office for National Statistic website. Population dan population density data are obtained from the estimation of the population for the UK, England and Wales, Scotland and Northern Ireland dataset for mid-2017. From that dataset, this study employs MYE5 which contain population and population density for local authorities in the UK from mid-2001 to mid-2017. This study only use data for 2015, which is data about population estimation in 2015. It is calculated based on census data in 2011. In addition, Gross Value Added as control variable data is obtain from regional Gross Value Added (Income Appoach) by Local Authority in 2015.

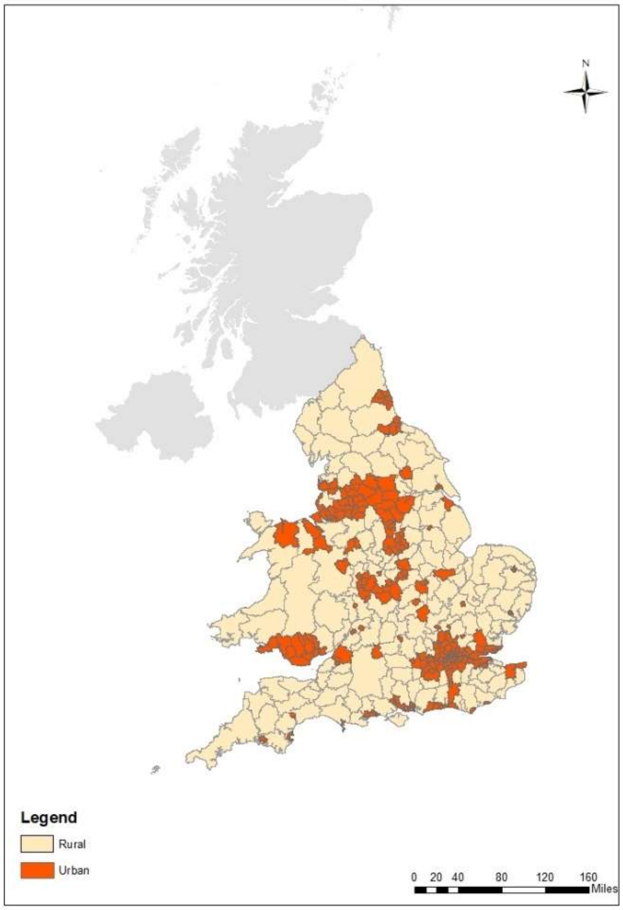
Different from the independent variables, the dependent variables data are obtained from two different sources. CO2 data was obtained from the Department for Business, Energy and Industrial Strategy in UK. The data is available from the table Local Authority CO2 emission estimates 2005 -2015 – Subset dataset. The table refers to local authority and regional estimates of CO2. This study only use data in 2015. Moreover, data about PM 2.5 and PM 10 were provided by National Atmospheric Emission Inventory (NAEI) website. The data are available from PM 2.5 emission map in 2015 and PM 10 emission map in 2015 at spatial resolution of 1 x 1 km.

As explained in Chapter 2, urban area definition in this study is referring to the Office for National Statistic UK which is 112 Major Town and Cities. However, during data collection period, it was found that the data existed only at the Local Authority District (LAD) level. According to Office for National Statistics (2018), when some data cannot be provided for smaller area than LAD, LAD can be used as proxy for urban. Therefore, due to the lack of data in in Major Town and Cities level, this study will use LAD as sample.

LAD is term for the local government in UK, refer to London boroughs, metropolitan districts, unitary authorities and non-metropolitan districts in England; unitary authorities in Wales; council areas in Scotland and district council areas in Northern Ireland (Office for National Statistics, 2016). LAD boundary cover urban core and rural countryside (Office for National Statistics, 2018). Therefore, using LAD level as unit analysis will be a challenge, because it might not illustrate real characteristic in urban area.

There are 348 LAD in England and Wales. Due to limitation LAD as urban area, this study tried to exclude rural area by adding rural – urban classification to address this issue. Rural – Urban classification is provided by Office for National Statistic in UK to create the boundaries between the two. LAD are classified as urban and rural area based on its urban population. The Office for National Statistic in UK use Output Area (OA) as basic area to classify urban and rural area. OA which have settlement with population of 10.000 and more are categorised as urban area, while all remaining OA are categorised as rural area (Office for National Statistics, 2018). By adding rural – urban classification, the amount of sample in this study reduce to 195 LAD. In addition, Greater London Area consists of 33 London boroughs. Then, this study aggregate data of 33 London borough to become one urban area. After all step are done, 163 urban LAD are utilized as sample in this study, as shown on Figure 3.

Figure 3 : Urban LAD



Source: Author (2018)

3.5 Validity and Reliability

Validity and reliability are important aspects in research. This research will used desk research as research strategy. Desk research will lead to valid answer of the question because desk research has high reliability and external validity (Van Thiel, 2014) because desk research using quantitative analysis that could allow generalization of the result. This research will use and analyse large number of variables, thus enable to generalize the result for England and Wales.

Regarding internal validity, source of the data which will be used in this research are provided by Official Organisation in UK, for instance Department for Business, Energy and Industrial Strategy in UK, National Atmospheric Emission Inventory (NAEI) and Office for National Statistic. Therefore, datasets in this study has internal validity because the data is produced by reputable organization.

3.6 Data Analysis Technique

There are two ways to analyzing quantitative data, which are descriptive statistical technique and inferential statistical techniques (Van Thiel, 2014). Descriptive statistical technique is used to analyse characteristic of variable and describe the data (Van Thiel, 2014). Inferential statistical techniques are used to analyse relations that are more explanatory statistic (Van Thiel, 2014).

This study used both of analysis method for quantitative data, which are descriptive analysis and inferential statistical analysis. Descriptive analysis is used to explain data about urban size, density CO_2 and particulate matter in urban area in England and Wales, then, inferential statistical analysis is used to analyse the correlation between urban size and density as independent variables and CO_2 emission and Particulate Matter as dependent variables.

Inferential statistical analysis which has been used in this study is regression analysis. Regression analysis is used to find correlation between variables (independent and dependent variable) and find out influence of independent variable to dependent variable. This study wants to find correlation between urban size and density with CO_2 and between urban size and density with particulate matter. Thus, this study used multiple regression as a method to find out the correlation between variables. Regression is done by using software Statistical Package for the Social Sciences (SPSS).

Correlation between independent variables should be done before conduct multiple regression analysis to avoid multicollinearity issue between variables. Table 2 show correlation result between independent variables. From that table, Pearson correlation between population and population density is 0,311, means two variables are not too strong correlated. Then, both of them can be used in multiple regression analysis.

Table 2 : Correlation Between Population and Density

Correlations

		Log Population	Log Density
Log Population	Pearson Correlation	1	,311**
	Sig. (2-tailed)		,000
	N	163	163
Log Density	Pearson Correlation	,311**	1
	Sig. (2-tailed)	,000	
	N	163	163

**. Correlation is significant at the 0.01 level (2-tailed).

To analyse two independent variables, the relationship between variables can be express through multiple regression function (Van Thiel, 2014). Gross Value Added as control variable added to the model. There are three model for each dependent variable. Model 1 use population as independent variable. Model 2 use population and population density as independent variable. Model 3 use population, population density and GVA. These models would be shown in the following equation:

<u>CO_2 as dependent variable</u>

Model 1

Log CO_2 = a + b_1 Log Population

Model 2

Log CO_2 = a + b_1Log Population + b_2 Log Population Density

Model 3

Log CO_2 = a + b_1 Log Population + b_2 Population Density + b_3 Log Gross Value Added

Particulate Matter 2.5 as dependent variable

Model 1

Log PM 2.5 = a + b_1 Log Population

Model 2

Log PM 2.5 = a + b_1Log Population + b_2 Log Population Density

Model 3

Log PM 2.5 = a + b_1 Log Population + b_2 Population Density + b_3 Log Gross Value Added

Particulate Matter 10 as dependent variable

Model 1

Log PM 2.5 = a + b_1 Log Population

Model 2

Log PM 10 = a + b_1 Log Population + b_2 Log Population Density

Model 3

Log PM 10 = a + b_1 Log Population + b_2 Log Population Density + b_3 Log Gross Value Added

Chapter 4: Research Design and Methods

4.1 Descriptive Analysis

4.1.1 CO2 Emission

There are two variables that will be explained in this section, which are total CO2 emission and CO2 Per capita in England and Wales. The data shows concentration of total CO2 emission in kilo tonnes and CO2 per capita in tonnes by Local Authority District in 2015. Total CO2 emissions are total CO2 from industry and commercial sector, domestic sector, and transport sector (Department for Business, Energy and Industrial Strategy, 2017). The average concentration of total CO2 emission is 1033,87 kilo tonnes and the average CO2 per capita is 4.6 tonnes. Figure 4 show distribution map of total CO2 emission in urban area of England and Wales. According to the map, the highest concentration shown in dark red are in London. There is also another high concentration CO2 in the upper part of England and Wales around Leeds, Sheffield and Bradford.

Figure 4 : Total CO2 Emission

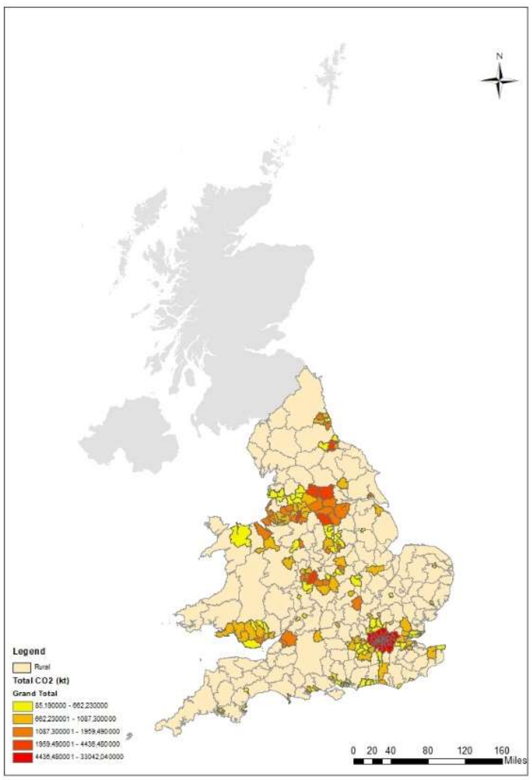


Figure 5 : CO2 Emision Per Capita

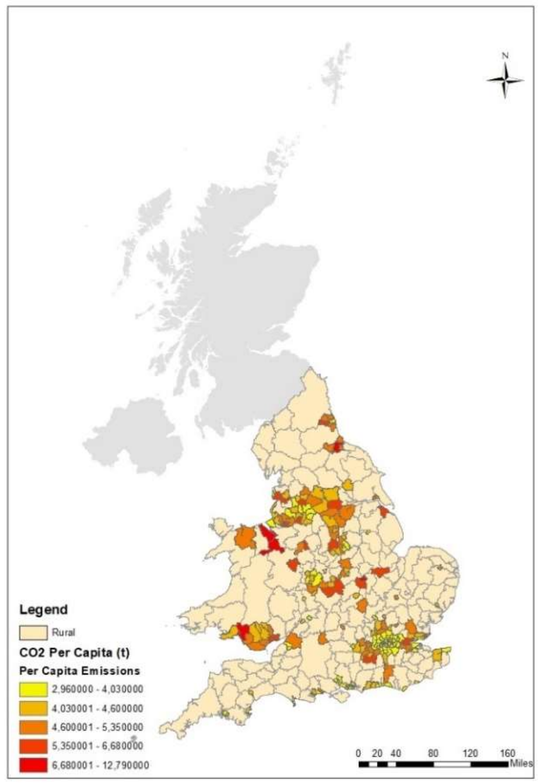


Figure 5 show distribution map of CO2 emission per capita in urban area of England and Wales in 2015. According to the map, the highest concentration shown in dark red spread in the north part of England and Wales. The lowest concentration of CO2 per capita is located in the south part of England and Wales.

4.1.2 Particulate Matter

There are two variables that will be explained in this section, which are total Particulate Matter (PM) 10 and total Particulate Matter (PM) 2.5 in England and Wales. The PM 2.5 and PM 10 data show concentration of PM 2,5 and PM 10 in tonnes per 1km^2 in 2015. The concentration of PM is concentration from combustion in energy production and transfer, combustion in commercial, institutions, residential and agricultural sectors, combustion in industry, production process, extraction or distribution of fossil fuel, solvent use, road transport, other transport and machinery, waste treatment and disposal, agricultural, forests and land use change and other sources and sinks (UK's National Atmospheric Emissions Inventory, 2017a, UK's National Atmospheric Emissions Inventory, 2017b). The average concentration of PM 2,5 is 248,94 tonnes per area and the average number of PM 10 is 322,57 tonnes per area. Figure 6 show map of concentration of PM 2,5 in urban area of England and Wales. According to the map, the highest concentration, shown in dark blue are in London. Similar with PM 2,5, the highest concentration of PM 10, shown in dark blue are in London, shown by Figure 7.

Figure 6 : Total PM 2.5

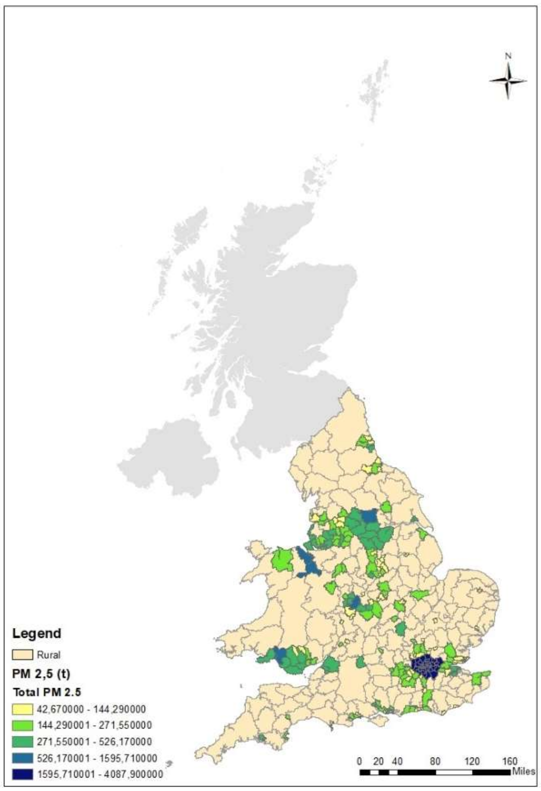
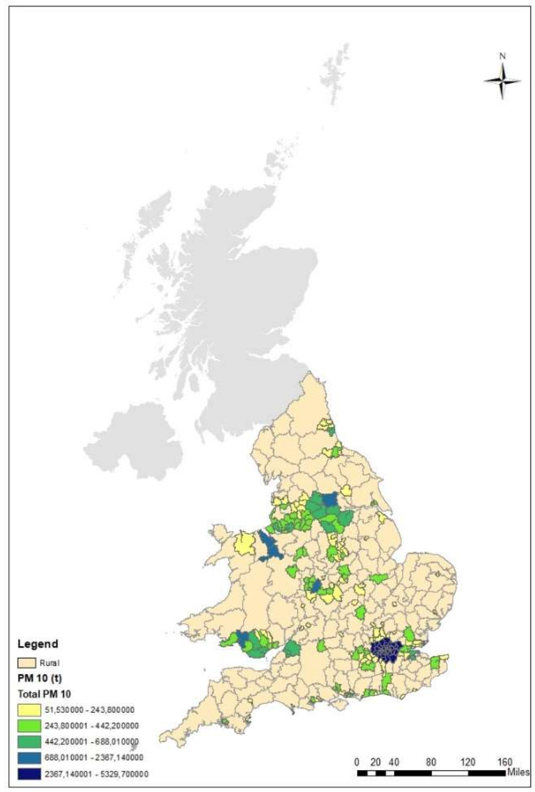


Figure 7 : Total PM 10



4.1.3 Population

Population data was obtained from Office for National Statistic of UK. It shows estimation of number of resident by Local Authority District in 2015. The estimation was calculated based on census data in 2011. The average population is 236.346 person. Figure 8 shows population map of England and Wales by urban area in 2015. As seen from the map, London is the highest population urban area in England and Wales, shown in red colour. The remaining urban area have medium and low population. Overall, distribution pattern of urban area with the highest population similar with urban area with the highest emitter city in term of CO2 emission, indicating there is correlation between population and CO2 emission. Further, the correlation between two variables will be analyzed using inferential analysis.

Figure 9 : Population

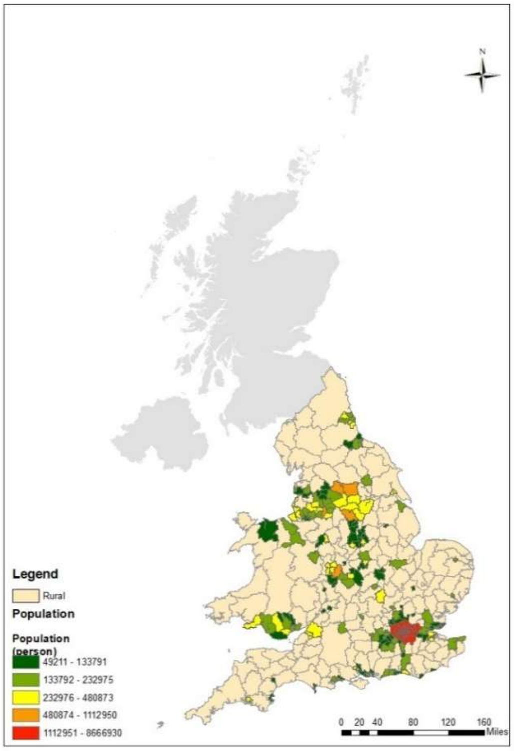
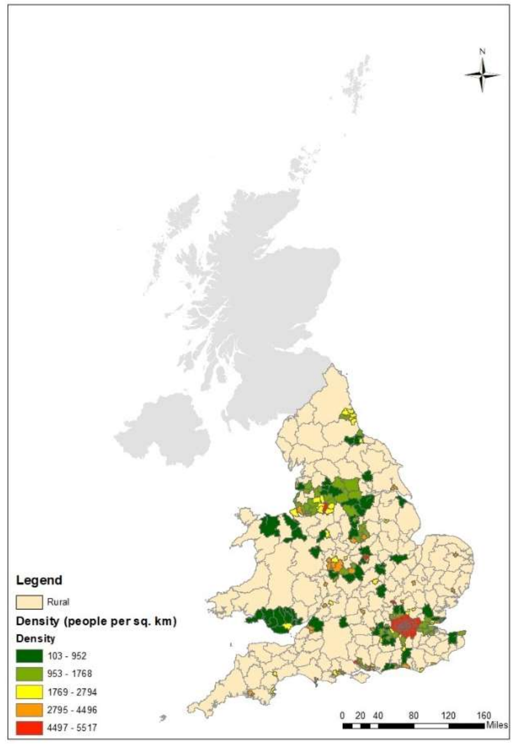


Figure 8 : Density



4.1.4 Density

Density data was obtained from Office for National Statistic of UK. It shows estimation of population density by Local Authority District in 2015. The estimation was calculated use census data in 2011. The average population density is 1.838 person per km^2. Figure 9 shows density map of England and Wales by urban area in 2015. As seen from the map, London is the highest density urban area in England and Wales, shown in red colour. The remaining urban areas have medium and low population. Overall, distribution pattern of urban area with the highest population similar with urban area with the highest emitter city in term of CO2 emission, indicating there is correlation between population and CO2 emission. Further, the correlation between two variables will be analyzed using inferential analysis.

4.2 Correlation Analysis

Correlation analysis is performed between independent, dependent and control variables. This analysis is used to find out the significance and strength of the linear relationship between two variables. Correlation between variable is described by value of pearson correlation to measure the strength of linear relationship. The value of Pearson correlation (r) range from – 1.00 (strong negative relationship) to + 1.00 (strong positive relationship). Together with pearson correlation, p value also has to be considered in correlation analysis. The p value is a number between 0.00 and 1.00, if p-value (sig.) below 0.05 indicates that there is difference or a relationship. Meanwhile if p-value (sig.) larger than 0.05 indicates that there is no difference or relationship.

Correlation analysis is important step before conduct multiple regression analysis. It will reveal significance and strength of the linear relationship between two variables. Significance relationship is needed between independent, dependent and control variables. However, significant and strong relationship between independent variables must be avoid to prevent from multicollinearity issue.

4.2.1 Correlation Between Independent Variable

This section discuss correlation between independent variable, which are population and population density. Correlation between independent variables can be showed using scatter plot and correlation table.

Figure 10 : Scatter Plot Population and Density

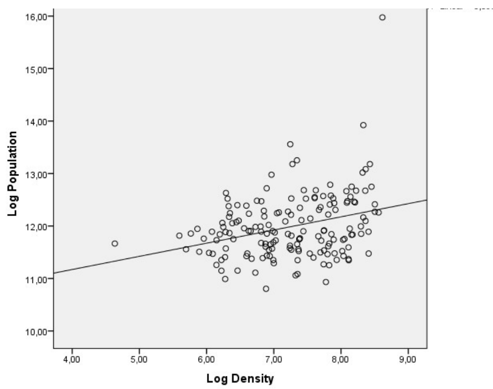


Table 3: Correlation Population and Density

Correlations

		Log Population	Log Density
Log Population	Pearson Correlation	1	,311**
	Sig. (2-tailed)		,000
	N	163	163
Log Density	Pearson Correlation	,311**	1
	Sig. (2-tailed)	,000	
	N	163	163

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 10 shows scatter plot between population and density as independent variables. As can be seen from that figure, there are weak correlation between population and density. From table 3, Pearson correlation between population and population density is 0,311, means variables are not too strong correlated between each other. In summary, based on scatter plot and correlation table, population does not have strong correlation with density. Meaning, both of them do not have collinearity issue and can be used to conduct multiple regression analysis.

4.2.1 Correlation Between Independent and Dependent Variables

This section discuss correlation between dependent variables and independent variables as well as control variable. First discussion is about correlation between CO2 emission as dependent variable and population and density as independent variables as well as Gross Value Added as control variable. Second discussion is about correlation between PM as dependent variable and population and density as independent variables as well as Gross Value Added as control variable. Correlation between these variables can be showed using scatter plot and correlation table.

4.2.1.1 CO2 Emission and Dependent Variables

<u>Total CO2 Emission</u>

Figure 12: Scatter Plot Population and Total CO2

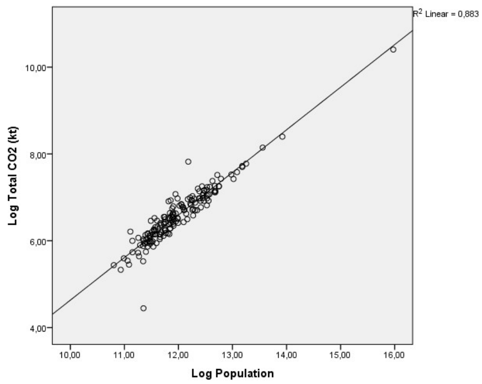


Figure 11 : Scatter Plot Density and Total CO2

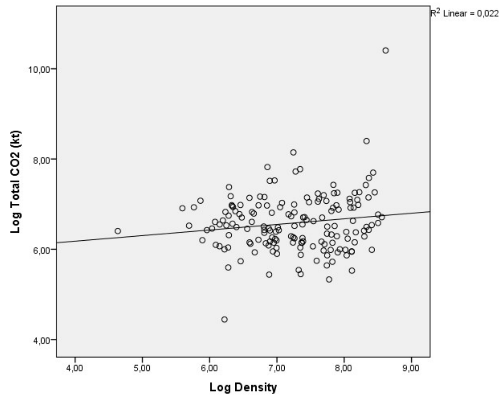
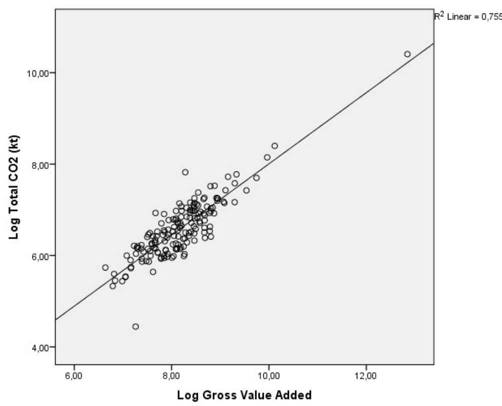


Figure 13 : Scatter Plot GVA and Total CO2



There is positive relationship between total CO2 emission and dependent variables as well as control variable. Correlation between total CO2 emission and population; and Gross Value Added show strong positive linear relationship. Meanwhile, correlation between total CO2 emission and density show not too strong positive linear relationship. The scatter plot illustrate that increase population, density and Gross Value Added will increase total CO2 emission.

Table 4 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,000	,903	1,107
	Log Density	,000	,903	1,107
	(Constant)	,000		
	Log Population	,000	,184	5,447
2	Log Density	,000	,869	1,151
	Log Gross Value Added	,001	,177	5,658

a. Dependent Variable: Log Total CO2 (kt)

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. There is no collinearity issue among variable if the value of VIF not more than 10. As seen from table 4, VIF value less than 10, meaning there is no collinearity issue among independent. Then multiple regression analysis can be conducted for this model.

<u>CO2 Per Capita</u>

There is negative relationship between CO2 Per Capita and dependent variables as well as control variable. Correlation between CO2 per capita and population, density and Gross Value Added show weak negative linear relationship. The scatter plot illustrate that increase population, density and Gross Value Added will decrease CO2 emission per capita.

Figure 15: Scatter Plot Population and CO2 Per Capita

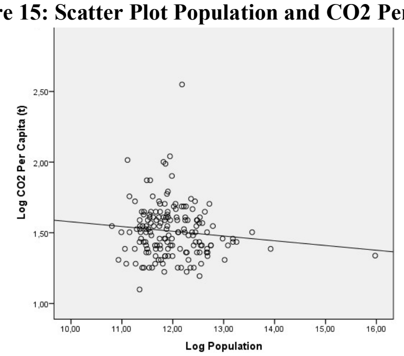


Figure 14 : Scatter Plot Density and CO2 Per Capita

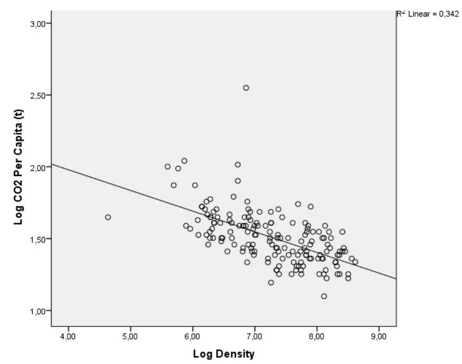


Figure 16 : Scatter Plot GVA and CO2 Per Capita

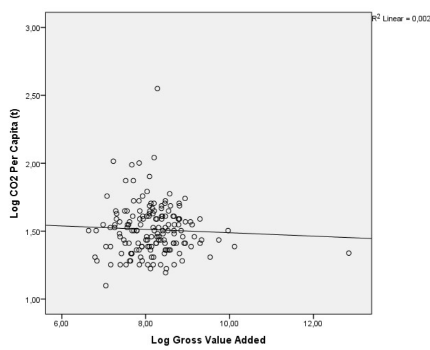


Table 5 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,240	,903	1,107
	Log Density	,000	,903	1,107
	(Constant)	,000		
2	Log Population	,004	,184	5,447
	Log Density	,000	,869	1,151
	Log Gross Value Added	,000	,177	5,658

a. Dependent Variable: Log CO2 Per Capita (t)

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. There is no collinearity issue among variable if the value of VIF not more than 10. As seen from table 5, VIF value less than 10, meaning there is no collinearity issue among independent. Then multiple regression analysis can be conducted for this model

4.2.1.2 Particulate Matter and Dependent Variables

Particular Matter 2.5

Figure 18 : Scatter Plot Between Population and PM 2.5

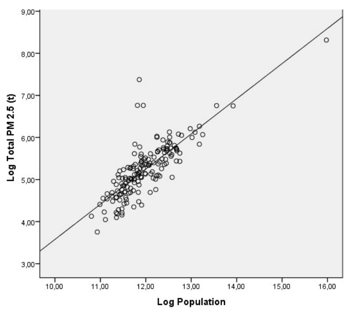


Figure 17 : Scatter Plot Between Density and PM 2.5

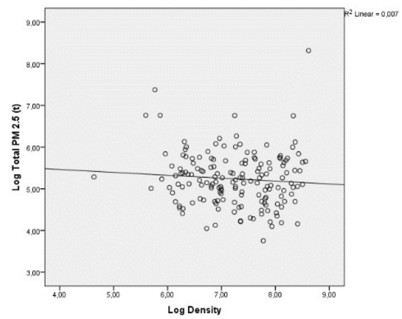
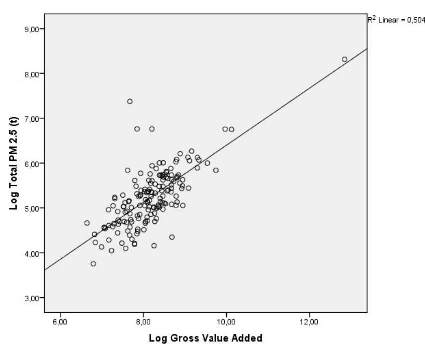


Figure 19 : Scatter Plot Between GVA and PM 2.5



There is positive relationship between total PM 2.5 and dependent variables as well as control variable. Correlation between total PM 2.5 and population and Gross Value Added show strong positive linear relationship. Meanwhile, correlation between total PM 2.5 and density show not strong negative linear relationship. The scatter plot illustrate that increase population and Gross Value Added will increase amount of total PM 2.5. On the other hand, increase density will decrease amount of total PM 2.5

Table 6 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,000	,903	1,107
	Log Density	,000	,903	1,107
2	(Constant)	,000		
	Log Population	,000	,184	5,447
	Log Density	,000	,869	1,151
	Log Gross Value Added	,332	,177	5,658

a. Dependent Variable: Log Total PM 2.5 (t)

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. There is no collinearity issue among variable if the value of VIF not more than 10. As seen from table 6, VIF value less than 10, meaning there is no collinearity issue among independent. Then multiple regression analysis can be conducted for this model.

Particular Matter 10

Figure 21 : Scatter Plot Between Population and PM 10

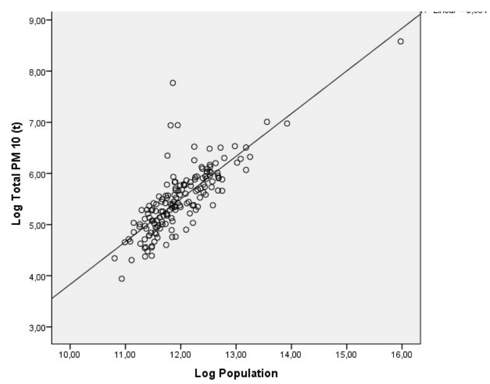


Figure 20 : Scatter Plot Between Density and PM 10

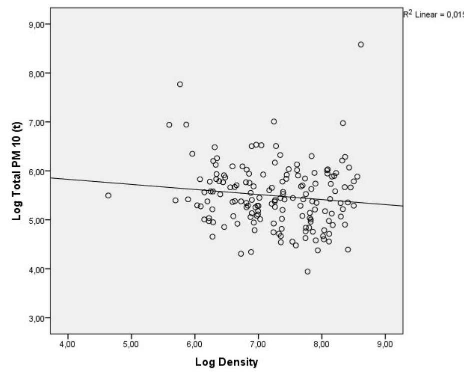
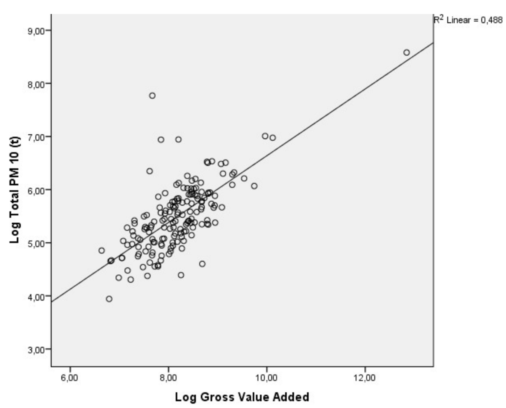


Figure 22 : Scatter Plot Between GVA and PM 10



There is positive relationship between total PM 10 and dependent variables as well as control variable. Correlation between total PM 10 and population and Gross Value Added show strong positive linear relationship. Meanwhile, correlation between total PM 10 and density show not too strong negative linear relationship. The scatter plot illustrate that increase population and Gross Value Added will increase amount of total PM 10. On the other hand, increase density will decrease amount of total PM 10.

Table 7 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,000	,903	1,107
	Log Density	,000	,903	1,107
	(Constant)	,000		
	Log Population	,000	,184	5,447
2	Log Density	,000	,869	1,151
	Log Gross Value Added	,437	,177	5,658

a. Dependent Variable: Log Total PM 10 (t)

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. There is no collinearity issue among variable if the value of VIF not more than 10. As seen from table 7, VIF value less than 10, meaning there is no collinearity issue among independent. Then multiple regression analysis can be conducted for this model.

4.3 Inferential Analysis

Regression analysis is performed between independent variables and dependent variables. There are two models in every dependent variable, then in total there are 8 models for 4 dependent variables with two independent variables and 1 control variable.

4.3.1 CO2 Emission

Multiple regression has been carried out to analyse to what extent population and population density influence CO2 emission. There are two variable of CO2 emission has been used in the multiple regression, which are total CO2 emission and CO2 per capita.

Total CO2 Emission

The result of multiple regression analysis between total CO2 emission as dependent variable and population and population density as independent variable is showed by table 8. There are three models which will be explained. Model 1 examine influence of population on total CO2 emission. Model 2 examine influence of population and population density on total CO2 emission. In model 3, GVA is added as control variable.

Table 8 : Regression Result for CO2 Emission

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-5,180	,339		-15,298	,000		
	Log Population	,981	,028	,939	34,781	,000	1,000	1,000
2	(Constant)	-4,822	,309		-15,585	,000		
	Log Population	1,033	,027	,989	38,766	,000	,903	1,107
	Log Density	-,136	,022	-,161	-6,293	,000	,903	1,107
3	(Constant)	-4,043	,381		-10,620	,000		
	Log Population	,863	,057	,826	15,046	,000	,184	5,447
	Log Density	-,149	,021	-,177	-7,016	,000	,869	1,151
	Log Gross Value Added	,167	,050	,186	3,327	,001	,177	5,658

a. Dependent Variable: Log Total CO2 (kt)

In all model, population is positively and statistically significant with total CO2 emission, indicating that increasing population will lead to increasing concentration of total CO2 emission. Meanwhile, population density is negatively and statistically significant with total

CO_2 emission in all model, indicating that increasing population density will lead to decreasing amount of total CO_2 emission.

In model 1, when there is a 1% rise in population, affects the increase of total CO_2 emission by 0.981%. This result show linear relationship between population and total CO emission, meaning large cities are not better than small cities in term of total CO_2 emission. Similarly, model 2 also show linear relationship between population and total CO_2 emission with addition to density, where increasing 1% in population increases total CO_2 emission by 1.033%. It means large cities are not more efficient than small cities in terms of total CO_2 emission. This is in accordance with previous result by Fragkias, Lobo, et al (2013), which found linear relationship between population and CO_2 emission, with including population density in the model. In addition, increasing 1% in population density in urban area in England and Wales, leads to decrease total CO_2 emission by 0,136 %. This means, high density cities have less concentration of CO_2 emission than low density cities. This result show same result with research by Lee and Lee (2014), which found that population density influences reduction of CO_2 emission in USA.

In model 3, GVA is statistically significant with total CO_2 emission. 1% increase in GVA is associated with increase of total CO_2 emission of 0.167 %. It means, increasing economic condition in urban areas increases concentration of total CO_2 emission. Moreover, addition of GVA decreases coefficient of population to 0,863 and increase coefficient of population density to 0.149. Increasing 1% population in urban area in England and Wales, leads to increasing total CO_2 emission by 0.863 %. This means large cities can be considered environmentally green, because doubling population will increase total CO_2 emission less than double. This finding is consistent with research by Rybski, Reusser et al (2017), which also found sublinear relationship between population and CO_2 emission in developed country, indicating that large cities have more advantage than small cities (Bettencourt, Lobo, et al., 2007). In addition, increasing 1% in urban population density in England and Wales, leads to decreasing total CO_2 emission by 0,149 %, implying denser the city is greener.

<u>CO_2 Emission Per Capita</u>

The result of multiple regression analysis between CO_2 emission per capita as dependent variable and population and population density as independent variable is showed by table 9. There are three model which will be explained. Model 1 examine influence of population on CO_2 emission per capita. Model 2 examine influence of population and population density on CO_2 emission per capita. In model 3, GVA is added as control variable.

Table 9 : Regression Result For CO2 Per Capita

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1,913	,286		6,686	,000		
	Log Population	-,034	,024	-,110	-1,407	,161	1,000	1,000
2	(Constant)	2,309	,237		9,732	,000		
	Log Population	,024	,020	,079	1,178	,240	,903	1,107
	Log Density	-,150	,017	-,609	-9,074	,000	,903	1,107
3	(Constant)	3,002	,288		10,409	,000		
	Log Population	-,127	,043	-,419	-2,932	,004	,184	5,447
	Log Density	-,162	,016	-,660	-10,053	,000	,869	1,151
	Log Gross Value Added	,148	,038	,568	3,906	,000	,177	5,658

a. Dependent Variable: Log CO2 Per Capita (t)

According to Table 9, population is not statistically significant, both in model 1 and 2 (p value > 0,05). Meaning population is not influence CO_2 per capita in both model. On the other hand, density is negatively and statistically significant in model 2 indicating that increasing population density lead to decreases concentration of CO2 per capita (Gudipudi, Fluschnik, et al., 2016). Increasing 1% in population density in urban area in England and Wales, leads to decreasing CO2 emission per capita by 0,150 %. It means, high density cities have less emission of CO2 emission per capita than low density cities.

In model 3, GVA is statistically significant with CO2 per capita. 1% increase in GVA is associated with increase CO2 per capita by 0.148 %. It means, increasing economic condition in urban area increase concentration of CO2 per capita. Moreover, addition of GVA influence coefficient value for population and density. When there is a 1% rise in population in England and Wales, will decrease concentration of CO2 emission per capita by 0.127 %. This means large cities have economic of scale in terms of environmental aspect. This result in line with previous model (model 3) using total CO2 emission as dependent. In that model, total CO2 emission increase less than population (coefficient is smaller than 1). Meanwhile, in this model, CO2 per capita decreasing. In addition, increasing 1% in urban population density in England and Wales, leads to decreases CO2 emission per capita by 0,162 %. It means high density cities have environmental benefit compared to low density cities.

4.3.2 Particulate Matter

Multiple regression has been carried out to analyse to what extent population and population density influence Particulate Matter. There are two variables of Particulate Matter has been used in the multiple regression, which are Particulate Matter 2.5 and Particulate Matter 10

Particulate Matter (PM) 2.5

The result of multiple regression analysis between PM 2.5 as dependent variable and population and population density is showed by table 10 . There are three model which will be explained. Model 1 examine influence of population on PM 2.5. Model 2 examine influence of population and population density on PM 2.5. In model 3, GVA is added as control variable.

Table 10 : Regression Result for PM 2.5

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-4,782	,591		-8,092	,000		
	Log Population	,836	,049	,801	16,978	,000	1,000	1,000
2	(Constant)	-3,964	,490		-8,086	,000		
	Log Population	,955	,042	,915	22,603	,000	,903	1,107
	Log Density	-,309	,034	-,367	-9,060	,000	,903	1,107
3	(Constant)	-3,592	,622		-5,774	,000		
	Log Population	,873	,094	,837	9,318	,000	,184	5,447
	Log Density	-,316	,035	-,375	-9,073	,000	,869	1,151
	Log Gross Value Added	,080	,082	,089	,973	,332	,177	5,658

a. Dependent Variable: Log Total PM 2.5 (t)

Population is positively and statistically significant with total PM 2.5 in all model, indicating that increasing population will lead to increasing total PM 2.5. Moreover, population density is negatively and statistically significant with total PM 2.5 in all model, indicating that increasing population density will lead to decreasing amount of total P 2.5. On the other hand, GVA is not statistically correlated to PM 2.5 in model 3 (p value > 0,05). It means, economic condition is not influence concentration of PM 2.5

In model 1, increasing 1% population in urban area in England and Wales, leads to increase PM 2.5 by 0.836%. When density is added to model 2, coefficient of population increase to 0.955 %. It means, when population increase by 1 %, then concentration of PM 2.5 will increase by 0.955 %. This result indicate there is almost linear relationship between population and PM

2.5, means large city is not more efficient than small city in terms of total amount of PM 2.5 I tonnes . Study by Han, Zhou, et al (2016) also have similar result, which found that population influence PM2.5 concentration.

In model 2, when there is a 1% rise in population density, decreases concentration of PM 2.5 by 0,309 %. It means, high density cities have less amount of PM 2.5 concentration in tonnes than low density cities. This is in accordance with previous study by Bereitschaft and Debbage (2013), which found that higher population density influence reduction of PM 2.5.

<u>Particulate Matter 10</u>
The result of multiple regression analysis between PM 10 as dependent variable and population and population density is showed by table 11. There are three model which will be explained. Model 1 examine influence of population on PM 10. Model 2 examine influence of population and population density on PM 10. In model 3, GVA is added as control variable.

Table 11 : Regression Result for PM 10

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-4,511	,599		-7,527	,000		
	Log Population	,834	,050	,796	16,710	,000	1,000	1,000
2	(Constant)	-3,596	,469		-7,674	,000		
	Log Population	,967	,040	,923	23,964	,000	,903	1,107
	Log Density	-,346	,033	-,409	-10,611	,000	,903	1,107
3	(Constant)	-3,311	,595		-5,563	,000		
	Log Population	,905	,090	,864	10,093	,000	,184	5,447
	Log Density	-,351	,033	-,415	-10,544	,000	,869	1,151
	Log Gross Value Added	,061	,078	,068	,779	,437	,177	5,658

a. Dependent Variable: Log Total PM 10 (t)

Population is positively and statistically significant with total PM10 in all model, indicating that increasing population lead to increases concentration of PM 10 in tonnes. In model 1, increasing 1% population in urban area in England and Wales, leads to increases PM 10 by 0.834%. Moreover when density is added to model 2, coefficient of population increase to 0.905% . If population increase by 1 %, concentration of PM 10 will increase by 0.905%. It means, large city is not more efficient than small city in terms of total amount of PM 10 in tonnes.

Population density is negatively and statistically significant with PM10 in all model, indicating that increasing population density will lead to decreasing concentration of PM 10 in tonnes. Increasing 1% in population density in urban area in England and Wales, leads to decreas PM 10 by 0,351%. It means, high density city will have less amount of PM 2.5 concentration than low density. This result is consistent with by Yuang, Song, et al (2017) which found that concentration of PM 10 is lower in high density cities than in low density cities.

In model 3, GVA is not statistically correlated to PM 10 (p value > 0,05). It means, economic condition is not influence concentration of PM 10. However, population and population density are significant in this model, means population and population density influence concentration of PM 10.

4.3.3 Limitation

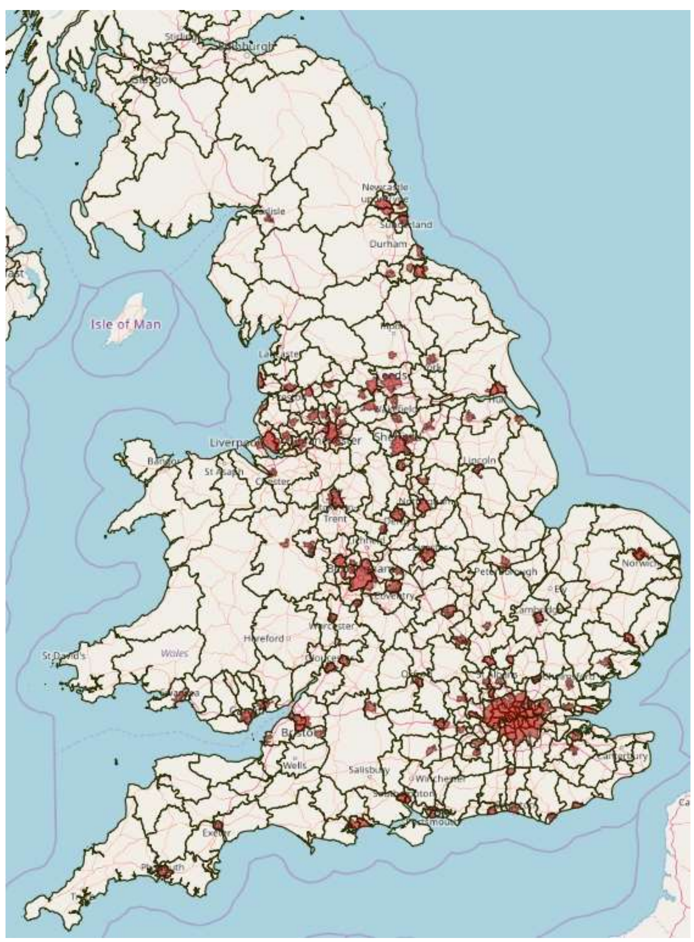
As mentioned before in Chapter 3, sample that was used for this regression is Urban Local Authority District (LAD) due to data availability. LAD is define based on administrative boundary, which might not reflect urban characteristic. The boundary covers not only urban area, but also rural area surrounding. Although the study already did some steps to overcome this issue, for instance only considering LAD which belong to urban area based on rural-urban classification by Office for National Statistic in UK and aggregate data for London, the accuracy of data is an issue of concern. The result from first regression might not illustrate the condition in urban area due to different boundary. As Louf and Barthelemy (2014a) argued that different ways to define urban area will lead to ambiguous result.

There is no general consensus about urban definition. However, this study want to analyse population, population density, CO_2 and PM in urban context due to the importance of urban area. Definition of urban area become an important aspect in explaining scaling exponent (β), because magnitude of scaling exponent very related to how urban areas is defined (Arcaute, Youn, et al., 2013). Therefore, this study did another regression analysis using Major Town and Cities as unit analysis, which illustrate urban characteristic in its definition.

4.4 Major Town and Cities

Major town and cities use built-up boundary to delineate the border. Built-up area where residential and/or workday population more than 75.000 people are categorised as major town and cities (Office for National Statistics, 2017a). Meanwhile, LAD use administrative boundary to delineate the border. Therefore, two different definition of urban area and city result different border of cities. As shown in Figure 23, there are differences in delineating urban area. Local Authority District border shown by black line and Major town and Cities border shown by red polygon.

Figure 23 : Boundary Difference Between Major Town Cities and LAD



There is limitation regarding data at Major and Town Cities level. Most of the data only available at LAD level for instance, population, population density, GVA and CO2 emission. Therefore, aggregate data from LAD level to urban area level is needed. As shown in Figure 24 - 26, delineation between LAD boundary and urban area boundary is very different. There are 3 different type of border (Figure 24, Figure 25 and Figure 26), which area (i) border of urban area is smaller than border of LAD, (ii) border of urban area is almost same with border of LAD, and (iii) border of urban area is bigger than border of LAD.

Figure 26 : Urban Area Smaller than LAD

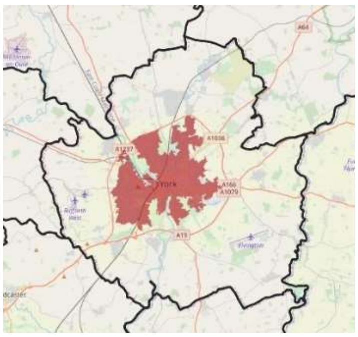
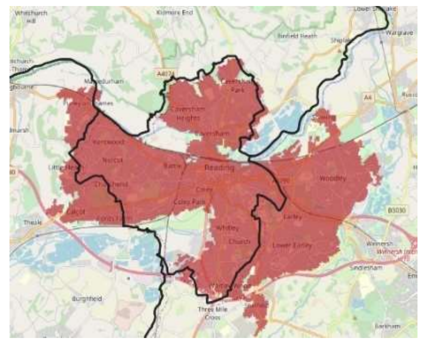


Figure 25 : Urban Area Almost Same with LAD

Figure 24 : Urban Area Bigger than LAD



However, due to availability of data, only 32 of 112 major town and cities which is used as sample. Calculation has been done to compare the area of major town and cities and LAD. By taking the cities with more or less 30% area difference between urban area and LAD boundaries, the research aimed at using LAD data whose boundaries have the least variance with actual urban area. Thus, resulting into more accurate urban area data from the LAD data. The samples are shown on table 12 below with green row.

Table 12 : Comparison Area Between Major Town and Cities and LAD

No	Major Town and Cities	LAD	Area (sq km)	Area LAD (sq km)	Percentage of Major Town and Cities area and LAD area (%)
1	Reading	Reading	58,14	40,39	144
2	Norwich	Norwich	52,62	39,01	135
3	Watford	Watford	28,70	21,43	134
4	Liverpool	Liverpool	123,31	111,81	110
5	Southampton	Southampton	53,54	49,90	107
6	Leicester	Leicester	78,32	73,32	107
7	Kingston upon Hull	Kingston upon Hull	73,63	71,43	103
8	Bristol	Bristol	112,46	109,67	103
9	Blackpool	Blackpool	34,47	34,84	99
10	Luton	Luton	40,74	43,34	94
11	Ipswich	Ipswich	36,94	39,51	93
12	Cambridge	Cambridge	37,62	40,69	92
13	Middlesbrough	Middlesbrough	49,01	53,88	91
14	Bournemouth	Bournemouth	40,26	46,17	87
15	Southend-on-Sea	Southend-on-Sea	36,15	41,75	87
16	Birmingham	Birmingham	229,13	267,73	86
17	Wolverhampton	Wolverhampton	59,33	69,42	85
18	Gloucester	Gloucester	34,54	40,54	85

No	Major Town and Cities	LAD	Area (sq km)	Area LAD (sq km)	Percentage of Major Town and Cities area and LAD area (%)
19	Manchester	Manchester	97,39	115,62	84
20	Nottingham	Nottingham	62,50	74,60	84
21	Slough	Slough	27,08	32,53	83
22	Stevenage	Stevenage	21,52	25,96	83
23	Portsmouth	Portsmouth	33,10	40,38	82
24	Stoke-on-Trent	Stoke-on-Trent	76,00	93,43	81
25	London	Greater London (region)	1242,73	1573,13	79
26	Lincoln	Lincoln	27,49	35,68	77
27	Worthing	Worthing	24,58	32,51	76
28	Derby	Derby	58,70	78,01	75
29	Plymouth	Plymouth	59,73	79,81	75
30	Coventry	Coventry	73,58	98,62	75
31	Worcester	Worcester	24,23	33,27	73
32	Oxford	Oxford	32,69	45,59	72
33	Poole	Poole	46,30	64,75	71
34	Hastings	Hastings	21,16	29,72	71
35	Northampton	Northampton	56,72	80,75	70
36	Cheltenham	Cheltenham	28,87	46,58	62
37	Harlow	Harlow	18,60	30,53	61
38	Exeter	Exeter	27,33	47,03	58
39	Crawley	Crawley	24,37	44,96	54
40	Eastbourne	Eastbourne	22,71	44,15	51
41	Newcastle upon Tyne	Newcastle upon Tyne	57,90	113,43	51
42	Cardiff	Cardiff	71,38	142,25	50
43	Woking	Woking	29,09	63,59	46
44	Redditch	Redditch	21,83	54,24	40
45	Chesterfield	Chesterfield	26,29	66,02	40
46	Brighton and Hove	Brighton and Hove	31,53	82,77	38
47	Sheffield	Sheffield	122,49	367,84	33
48	Mansfield	Mansfield	22,70	76,68	30
49	Sunderland	Sunderland	39,14	137,41	28
50	Bolton	Bolton	37,84	139,76	27
51	Nuneaton	Nuneaton and Bedworth	21,08	78,93	27
52	Hartlepool	Hartlepool	23,51	93,54	25
53	Warrington	Warrington	44,89	180,58	25
54	Dudley	Dudley	23,35	97,93	24
55	Basildon	Basildon	25,51	110,00	23
56	South Shields	South Tyneside	14,86	64,38	23
57	Bury	Bury	22,23	99,44	22
58	West Bromwich	Sandwell	18,60	85,54	22
59	Preston	Preston	30,51	142,26	21
60	Blackburn	Blackburn with Darwen	29,27	136,99	21

No	Major Town and Cities	LAD	Area (sq km)	Area LAD (sq km)	Percentage of Major Town and Cities area and LAD area (%)
61	Gateshead	Gateshead	30,17	142,32	21
62	Leeds	Leeds	111,63	551,57	20
63	Swindon	Swindon	46,17	230,04	20
64	Stockport	Stockport	24,65	126,01	20
65	St Helens	St Helens	26,46	136,33	19
66	Salford	Salford	18,83	97,17	19
67	Bradford	Bradford	70,00	366,33	19
68	Bracknell	Bracknell Forest	20,58	109,36	19
69	Newport	Newport	34,72	190,48	18
70	Solihull	Solihull	31,23	178,24	18
71	Burnley	Burnley	18,94	110,66	17
72	Rochdale	Rochdale	25,34	158,09	16
73	Telford	Telford and Wrekin	46,19	290,24	16
74	Sutton Coldfield	Birmingham	41,71	267,73	16
75	Milton Keynes	Milton Keynes	45,67	308,55	15
76	Southport	Sefton	22,93	154,95	15
77	Walsall	Walsall	15,21	103,95	15
78	Oldham	Oldham	19,68	142,31	14
79	Birkenhead	Wirral	21,22	157,01	14
80	Swansea	Swansea	49,08	379,57	13
81	Peterborough	Peterborough	43,77	343,29	13
82	York	York	33,70	271,87	12
83	Grimsby	North East Lincolnshire	23,38	191,82	12
84	St Albans	St Albans	18,66	161,17	12
85	Huddersfield	Kirklees	46,75	408,45	11
86	Darlington	Darlington	22,55	197,43	11
87	Gillingham	Medway	21,81	193,49	11
88	Hemel Hempstead	Dacorum	23,47	212,43	11
89	Wigan	Wigan	20,44	188,13	11
90	Rotherham	Rotherham	30,82	286,46	11
91	Stockton-on-Tees	Stockton-on-Tees	21,73	204,91	11
92	Colchester	Colchester	31,52	333,10	9
93	Newcastle-under-Lyme	Newcastle-under-Lyme	19,66	210,91	9
94	Wakefield	Wakefield	29,27	338,54	9
95	Chatham	Medway	15,95	193,49	8
96	High Wycombe	Wycombe	25,97	324,49	8
97	Barnsley	Barnsley	25,68	329,00	8
98	Guildford	Guildford	20,76	270,87	8
99	Chelmsford	Chelmsford	25,71	342,17	8
100	Bath	Bath and North East Somerset	24,24	351,04	7
101	Maidstone	Maidstone	25,45	393,24	6
102	Halifax	Calderdale	20,37	363,87	6
103	Doncaster	Doncaster	31,09	567,88	5

No	Major Town and Cities	LAD	Area (sq km)	Area LAD (sq km)	Percentage of Major Town and Cities area and LAD area (%)
104	Burton upon Trent	East Staffordshire	20,54	389,89	5
105	Weston-Super-Mare	North Somerset	18,84	374,55	5
106	Basingstoke	Basingstoke and Deane	29,19	633,66	5
107	Bedford	Bedford	20,17	476,29	4
108	Scunthorpe	North Lincolnshire	26,71	846,09	3
109	Chester	Cheshire West and Chester	23,62	916,48	3
110	Carlisle	Carlisle	18,92	1039,04	2
111	Harrogate	Harrogate	18,08	1308,81	1
112	Shrewsbury	Shropshire	21,49	3196,50	1

Source : Author (2018)

4.4.1 Correlation Analysis

Correlation analysis is performed between independent, dependent and control variables. This analysis is used to find out the significance and strength of the linear relationship between two variables. Correlation analysis is important step before conduct multiple regression analysis. It will reveal significance and strength of the linear relationship between two variables. Significance relationship is needed between independent, dependent and control variables. However, significant and strong relationship between independent variables must be avoid to prevent from multicollinearity issue.

4.4.1.1 Correlation Between Independent Variable

This section discuss correlation between independent variables, which are population and population density. Correlation between independent variables can be showed using scatter plot and correlation table.

Figure 27 : Scatter Plot Population and Density

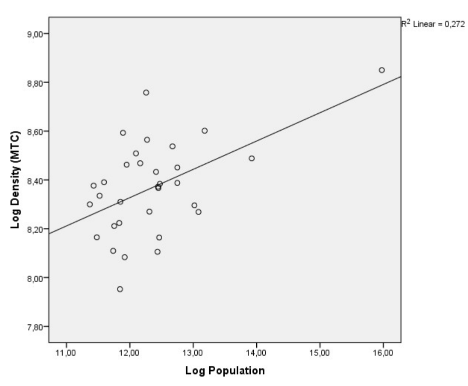


Table 13: Correlation Population and Density

Correlations

		Log Population	Log Density (MTC)
Log Population	Pearson Correlation	1	,522**
	Sig. (2-tailed)		,002
	N	32	32
Log Density (MTC)	Pearson Correlation	,522**	1
	Sig. (2-tailed)	,002	
	N	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 27 shows scatter plot between population and density as independent variables. As can be seen from that figure, there are weak correlation between population and density. From table 13, Pearson correlation between population and population density is 0,522, means variables are not correlated between each other. In summary, based on scatter plot and correlation table, population does not have strong correlation with density. Meaning, both of them do not have collinearity issue and can be used to conduct multiple regression analysis.

4.4.1.2 Correlation Between Independent and Dependent Variables

This section discuss correlation between dependent variables and independent variables as well as control variable. First discussion is about correlation between CO2 emission as dependent variable and population and density as independent variables as well as Gross Value Added as control variable. Second discussion is about correlation between PM as dependent variable and population and density as independent variables as well as Gross Value Added as control variable. Correlation between these variables can be showed using scatter plot and correlation table.

4.4.1.2.1 CO2 Emission and Dependent Variables

Total CO2 Emission

Figure 29: Scatter Plot Population and Total CO2

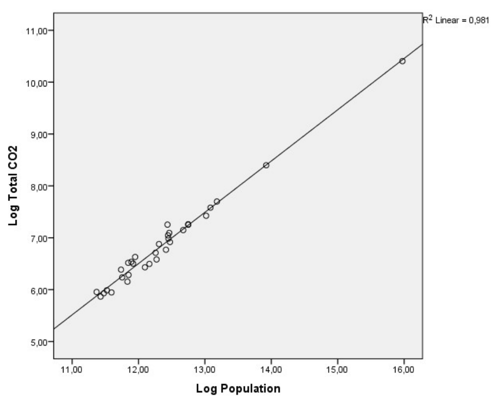


Figure 28 : Scatter Plot Density and Total CO2

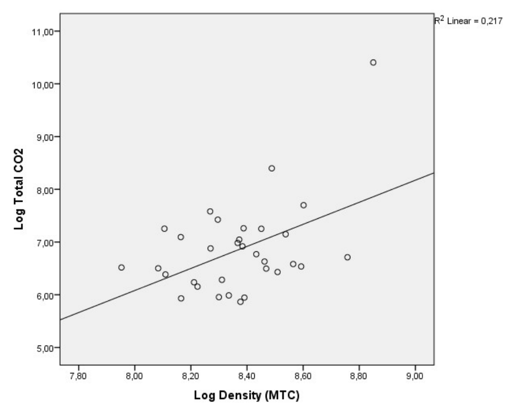


Figure 30 : Scatter Plot GVA and Total CO2

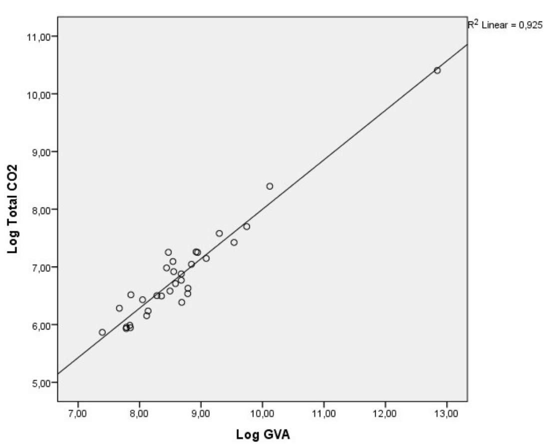


Table 14 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,000	,728	1,374
	Log Density (MTC)	,014	,728	1,374
	(Constant)	,040		
2	Log Population	,000	,077	12,988
	Log Density (MTC)	,004	,699	1,430
	Log GVA	,031	,074	13,505

There is positive relationship between total CO2 emission and dependent variables as well as control variable. Correlation between total CO2 emission and population; and Gross Value Added show strong positive linear relationship. Meanwhile, correlation between total CO2 emission and density show not too strong positive linear relationship. The scatter plot illustrate that increase population, density and Gross Value Added will increase total CO2 emission.

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. As seen from table 14, model with population, population density and GVA has VIF value more than 10, meaning there is collinearity issue among independent. Then multiple regression analysis cannot be conducted for this model.

CO2 Per Capita

There is negative relationship between CO2 Per Capita and dependent variables as well as control variable. Correlation between CO2 per capita and population, density and Gross Value Added show weak negative linear relationship. The scatter plot illustrate that increase population, density and Gross Value Added will decrease CO2 emission per capita.

Figure 32: Scatter Plot Population and CO2 Per Capita

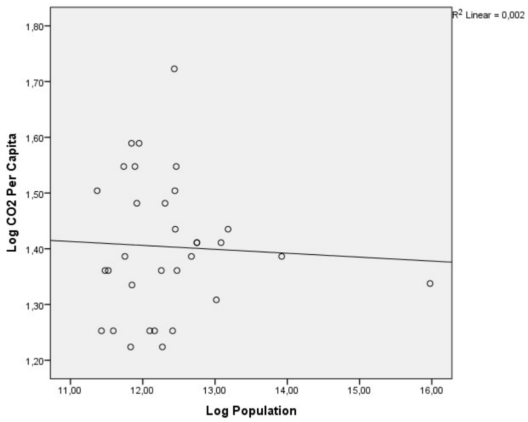


Figure 31 : Scatter Plot Density and CO2 Per Capita

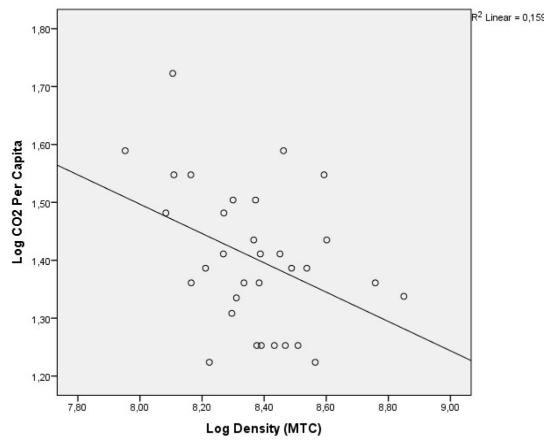


Figure 33 : Scatter Plot GVA and CO2 Per Capita

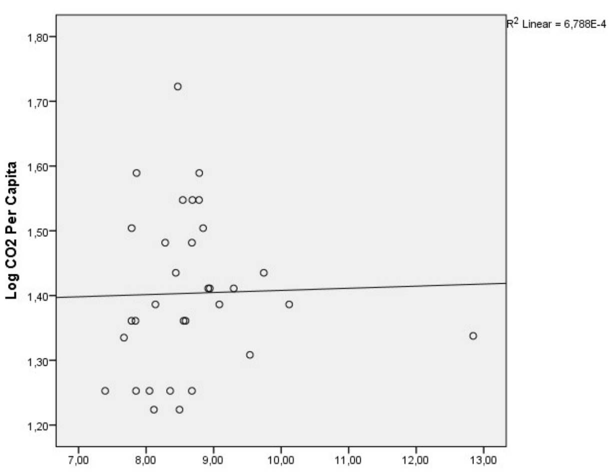


Table 15 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,274	,728	1,374
	Log Density (MTC)	,014	,728	1,374
	(Constant)	,000		
3	Log Population	,083	,077	12,988
	Log Density (MTC)	,003	,699	1,430
	Log GVA	,028	,074	13,505

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. As seen from table 15, model with population, population density and GVA has VIF value more than 10, meaning there is collinearity issue among independent. Then multiple regression analysis cannot be conducted for this model.

4.4.1.2.2 Particulate Matter and Dependent Variables

Particular Matter 2.5

Figure 35 : Scatter Plot Between Population and PM 2.5

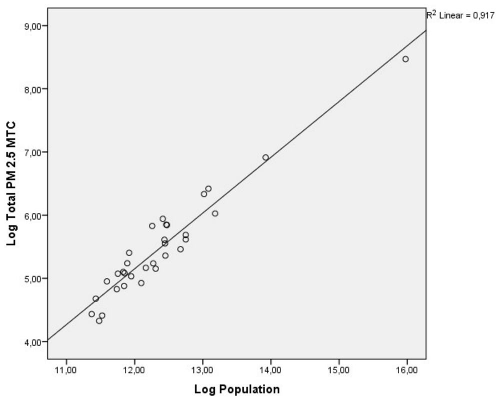


Figure 34 : Scatter Plot Between Density and PM 2.5

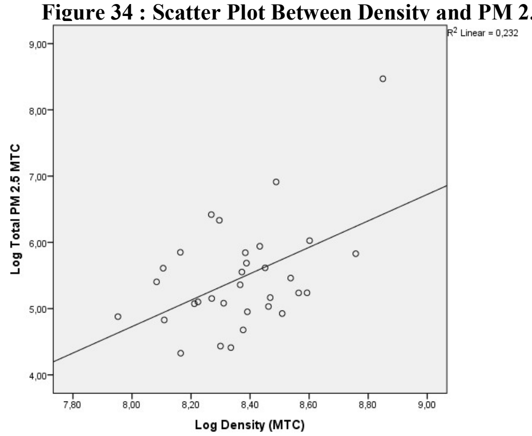


Figure 36 : Scatter Plot Between GVA and PM 2.5

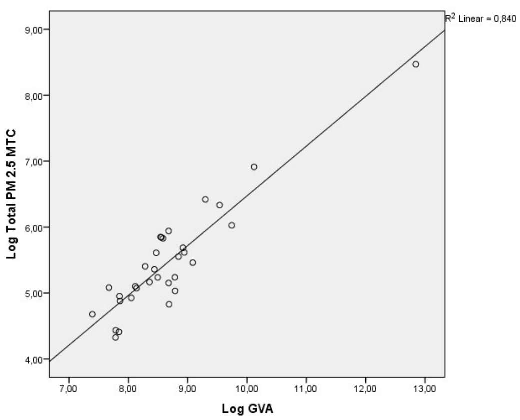


Table 16 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,000	,728	1,374
	Log Density (MTC)	,685	,728	1,374
	(Constant)	,037		
2	Log Population	,000	,077	12,988
	Log Density (MTC)	,718	,699	1,430
	Log GVA	,879	,074	13,505

There is positive relationship between total PM 2.5 and dependent variables as well as control variable. Correlation between total PM 2.5 and population and Gross Value Added show strong positive linear relationship. Meanwhile, correlation between total PM 2.5 and density do not show strong negative linear relationship. The scatter plot illustrate that increase population and Gross Value Added will increase amount of total PM 2.5. On the other hand, increase density will decrease amount of total PM 2.5

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. As seen from table 16, model with population, population density and GVA has VIF value more than 10, meaning there is collinearity issue among independent. Then multiple regression analysis cannot be conducted for this model.

Particular Matter 10

Figure 38 : Scatter Plot Between Population and PM 10

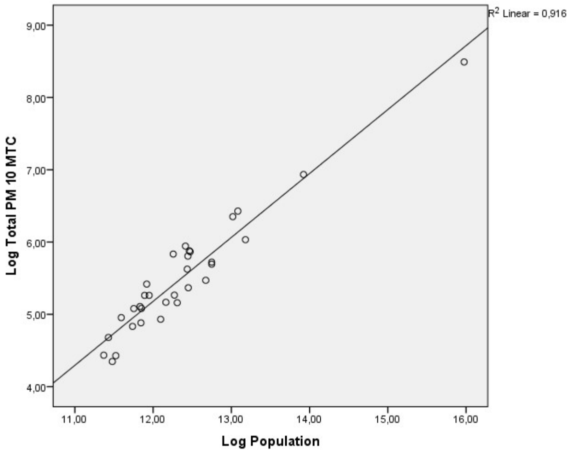


Figure 37 : Scatter Plot Between Density and PM 10

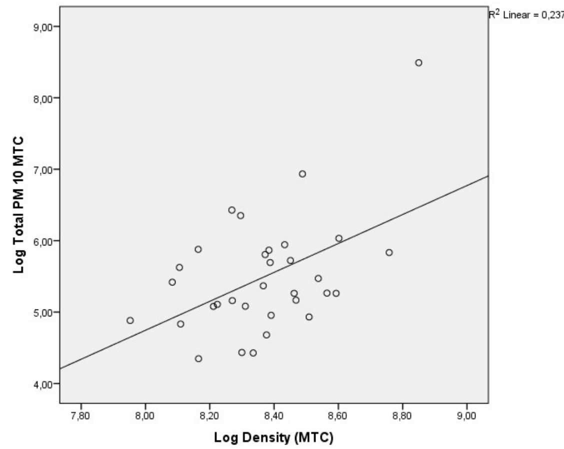


Figure 39 : Scatter Plot Between GVA and PM 10

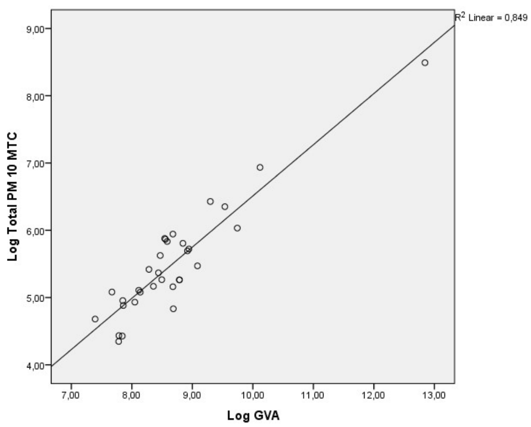


Table 17 : VIF Population and Density

Model		Sig.	Collinearity Statistics	
			Tolerance	VIF
1	Log Population	,000	,728	1,374
	Log Density (MTC)	,790	,728	1,374
	(Constant)	,046		
2	Log Population	,000	,077	12,988
	Log Density (MTC)	,768	,699	1,430
	Log GVA	,844	,074	13,505

There is positive relationship between total PM 10 and dependent variables as well as control variable. Correlation between total PM 10 and population and Gross Value Added show strong positive linear relationship. Meanwhile, correlation between total PM 10 and density show not too strong negative linear relationship. The scatter plot illustrate that increase population and Gross Value Added will increase amount of total PM 10. On the other hand, increase density will decrease amount of total PM 10.

To conduct multiple regression analysis, need to consider VIF (Variance Inflation Factor) value to prevent collinearity among the independent variables in this model. As seen from table 17, model with population, population density and GVA has VIF value more than 10, meaning there is collinearity issue among independent. Then multiple regression analysis cannot be conducted for this model.

4.4.2 Inferential Analysis

Regression analysis is performed between independent variables and dependent variables. There are two models in every dependent variable, then in total there are 8 models for 4 dependent variables with two independent variables and 1 control variable

4.4.2.1 CO2 Emission

Multiple regression has been carried out to analyse to what extent population and population density influence CO2 emission. There are two variable of CO2 emission has been used in the multiple regression, which are total CO2 emission and CO2 per capita.

Total CO2 Emission

The result of multiple regression analysis between total CO2 emission as dependent variable and population and population density is showed by table 18. There are three model which will be explained. Model 1 examine influence of population on total CO2 emission. Model 2 examine influence of population and population density on total CO2 emission. In model 3, GVA is added as control variable.

Table 18 : Regression Result for Total CO2

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-5,359	,311		-17,246	,000		
	Log Population	,988	,025	,990	39,391	,000	1,000	1,000
2	(Constant)	-3,169	,887		-3,571	,001		
	Log Population	1,025	,027	1,027	38,061	,000	,728	1,374
	Log Density (MTC)	-,316	,121	-,070	-2,606	,014	,728	1,374
3	(Constant)	-2,068	,960		-2,154	,040		
	Log Population	,859	,077	,860	11,091	,000	,077	12,988
	Log Density (MTC)	-,368	,116	-,082	-3,180	,004	,699	1,430
	Log GVA	,160	,071	,180	2,276	,031	,074	13,505

a. Dependent Variable: Log Total CO2

Population is positively and statistically significant with total CO2 emission in every model, indicating that increasing population leads to increasing concentration of total CO2 emission. On the other hand, population density is negatively and statistically significant with total CO2 emission only in model 3, indicating that increasing population density leads to decreasing amount of total CO2 emission.

In model 1, when there is a 1% rise in population, affects the increase of total CO2 emission by 0.988%. This result show linear relationship between population and total CO emission, meaning large city is better than small city in term of total CO2 emission. In model 2, the coefficient of population increases with addition of density to 1.025 %. It means, increasing 1% population in urban area in England and Wales, leads to increases total CO2 emission by 1.025 %. This means, large cities are not more efficient than small cities in terms of total amount of CO2 emission. This result in line with study by Mojari, Gudmundsson, et al., (2015), which found linear relation between population and CO2 emission.

GVA is not statistically correlated to total CO2 emission in model 3 (p value > 0,05), indicating GVA is not influence concentration of total CO2. Moreover, VIF values for population and GVA are greater than 10, indicating there is collinearity in this model. Thus, the model becoming biased.

CO2 Percapita

The result of multiple regression analysis between CO2 emission per capita as dependent variable and population and population density is showed by table 19. There are three model which will be explained. Model 1 examine influence of population on CO2 emission per capita.

Model 2 examine influence of population and population density on CO2 emission per capita. In model 3, GVA is added as control variable.

Table 19 : Regression Result For CO2 Per Capita

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1,490	,318		4,683	,000		
	Log Population	-,007	,026	-,050	-,273	,786	1,000	1,000
2	(Constant)	3,747	,908		4,128	,000		
	Log Population	,031	,028	,218	1,115	,274	,728	1,374
	Log Density (MTC)	-,325	,124	-,513	-2,625	,014	,728	1,374
3	(Constant)	4,887	,980		4,989	,000		
	Log Population	-,142	,079	-1,007	-1,798	,083	,077	12,988
	Log Density (MTC)	-,379	,118	-,598	-3,214	,003	,699	1,430
	Log GVA	,166	,072	1,321	2,312	,028	,074	13,505

a. Dependent Variable: Log CO2 Per Capita

Population is not statistically significant, both in model 1 and 2 (p value > 0,05). Meaning population is not influence CO2 per capita in both models. On the other hand, density is negatively and significantly significant in model 3 indicating that increasing population density will lead to decreasing concentration of total CO2 emission. 1% in population density in urban area in England and Wales, leads to decreasing CO2 emission per capita by 0,379 %. It means, high density city will have less amount of CO2 emission per capita than low density city. In addition, GVA is not statistically correlated to total CO2 emission in model 3 (p value > 0,05). Implying GVA is not influence concentration of CO2 per capita. Moreover, VIF values for population and GVA are greater than 10, then there is collinearity in this model. Thus, the model becoming biased.

4.4.2.2 Particulate Matter

Multiple regression has been carried out to analyse to what extent population and population density influence Particulate Matter. There are two variables of Particulate Matter has been used in the multiple regression, which are Particulate Matter 2.5 and Particulate Matter 10

<u>Particulate Matter 2.5</u>

The result of multiple regression analysis between PM 2.5 as dependent variable and population and population density is showed by table 15. There are three model which will be explained. Model 1 examine influence of population on PM 2.5. Model 2 examine influence of population and population density on PM 2.5. In model 3, GVA is added as control variable.

Table 20 : Regression Result For PM 2.5

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-5,434	,598		-9,082	,000		
	Log Population	,882	,048	,958	18,257	,000	1,000	1,000
2	(Constant)	-4,700	1,893		-2,483	,019		
	Log Population	,894	,057	,971	15,569	,000	,728	1,374
	Log Density (MTC)	-,106	,259	-,026	-,409	,685	,728	1,374
3	(Constant)	-4,873	2,229		-2,186	,037		
	Log Population	,921	,180	1,000	5,124	,000	,077	12,988
	Log Density (MTC)	-,098	,268	-,024	-,364	,718	,699	1,430
	Log GVA	-,025	,164	-,031	-,154	,879	,074	13,505

a. Dependent Variable: Log Total PM 2.5 MTC

As shown as Table 20, only population which statistically significant with PM 2.5, other variables are not statistically significant with PM 2.5 (p-value > 0,05) means total PM 2,5 is influenced by population in urban area in England and Wales. Moreover, there is sublinear relationship between population and PM 2.5 in model 1, means large city produced less PM 2.5 in tonnes compared to small city.

Particulate Matter 10

The result of multiple regression analysis between PM 10 as dependent variable and population and population density is showed by table 21. There are three model which will be explained. Model 1 examine influence of population on PM 10. Model 2 examine influence of population and population density on PM 10. In model 3, GVA is added as control variable.

Table 21 : Regression Result For PM 10

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-5,435	,607		-8,951	,000		
	Log Population	,885	,049	,957	18,040	,000	1,000	1,000
2	(Constant)	-4,946	1,924		-2,571	,016		
	Log Population	,893	,058	,966	15,288	,000	,728	1,374
	Log Density (MTC)	-,071	,263	-,017	-,268	,790	,728	1,374
3	(Constant)	-4,719	2,265		-2,084	,046		
	Log Population	,858	,183	,929	4,702	,000	,077	12,988
	Log Density (MTC)	-,081	,273	-,020	-,298	,768	,699	1,430
	Log GVA	,033	,166	,040	,199	,844	,074	13,505

a. Dependent Variable: Log Total PM 10 MTC

According to table 21, only population which statistically significant with PM 10, other variables are not statistically significant with PM 10 (p-value > 0,05) means only population which influence total PM 10 among these variables in urban area in England and Wales. In model 1, there is sublinear relationship between population and PM 10, means large city is more efficient than small city in terms of total amount of PM 10 in tonnes.

Chapter 5: Conclusions and Recommendations

5.1 Conclusion

The main objective of this study is to analyse the correlation between urban size and density and CO2 emission and Particulate Matter in England and Wales. There are two independent regression analysis which has been conducted between population, population density, GVA and CO2 emission and PM, using urban LAD and major town and cities as sample.

Using urban LAD as unit analysis, it is found that population and population density are statistically significant with CO2. This result is consistent with previous studies on population, population density and CO2 emission (Fragkias, Lobo, et al., 2013, Lee and Lee, 2014, Oliveira, Andrade Jr, et al., 2014, Louf and Barthelemy, 2014b, Mohajeri, Gudmundsson, et al., 2015, Gudipudi, Fluschnik, et al., 2016). There is a linear relationship between population and CO emission. Implying that large urban area in England and Wales are not more efficient than small ones in terms of total CO2 emission. This is in accordance with previous result by Fragkias, Lobo, et al (2013), which found linear relationship between population and CO2 emission, with including population density in the model. Moreover, significant relationship between density and CO2 emission means that urban area with high density has less concentration of CO2 emission than urban area with low density. This result support previous study by Lee and Lee (2014) which found population density significantly influence CO2 emission in urban areas in UK. This result also confirm notion of compact city that have environmental benefit. Urban area with high density characteristic can reduce need to travel due to close proximity among facilities thus will reduce energy fuel consumption (Neuman, 2005). From this result, population and density influence CO2 emission in urban LAD in England and Wales. However, the influence of those variable on CO2 when is analysed together are not significant, shown by linear relationship between population and CO2 emission. The result contrary with concept that large cities offer economies of scale, means large cities are more efficient in energy use compare to small cities. As argued by Fragkias, Lobo, et al (2013), linear relationship can be explain using energy and emission relation. In large cities, energy efficiencies are weaken by consume fuel consumption intensively. Therefore, there is no significant different between large cities and small cities in terms of energy efficiency.

Furthermore, controlling GVA for population and population density, showing sub-linear relationship. Implying that large urban areas in England and Wales are more environmentally friendly compare to small urban areas. This is consistent with research by Rybski, Reusser et al (2017), which found cities in developed countries have sub-linear relation with CO2 emission. The finding confirms economies of scale in large cities (Bettencourt, Lobo, et al., 2007). Large cities are considered have more advantage than small ones. Provision of infrastructure and energy consumption in large cities are more efficient than in small cities, thus lead to minimize CO2 emissions released (Fragkias, Lobo, et al., 2013, Dodman, 2009a, Glaeser and Kahn, 2008, Bettencourt, Lobo, et al., 2007).

However, this finding is contrary with study by Oliveira, Andrade, Jr, et al (2014), which found super linear relationship between population and CO2 emission. They claimed that large cities are not environmentally friendly, because if the population increase the emission will increase more than increasing of population. Based on this study, large cities emit more CO2 emission compare to small one.

The difference result between this study and study by Oliveira, Andrade, Jr, et al (2014) is due to use different urban boundary. Oliveira, Andrade, Jr, et al (2014) define urban based on spatial continuity. Meanwhile this regression has used urban data based on urban LAD, which is administrative boundary. Although, this study already excludes the rural area in LAD, this boundary still has limitation. Difference method to delineate urban area has become a concern for many researches due to ambiguity result. Gudipudi, Fluschnik, et al (2016) pointed out that no definite urban definition will be a challenge in environmental assessment for instance calculating CO2 emission in urban area. Moreover, how urban is define really influence scaling exponent, consequently can led to misleading conclusion. Heterogeneity definition of urban area become an issue in scaling analysis (Arcaute, Youn, et al., 2013, Louf and Barthelemy, 2014a).

Based on analysis, population and population density also influence concentration of PM. This result is consistent with previous studies on population, population density and concentration of PM (Bereitschaft and Debbage, 2013, Kashem, Irawan, et al., 2014, McCarty and Kaza, 2015, Han, Zhou, et al., 2016). There is sublinear relationship between population and PM. It means large urban areas in English and Wales is more efficient than small ones in term of concentration of PM. This result is consistent with study by Han, Zhou, et al (2016), which found that population influence PM2.5 concentration. Sublinear relationship between population PM can be explained with compliance of environmental policy. Study by Muller and Jha (2017) found sub-linear relationship between population and air pollution in urban area which successfully achieve target of air pollution policy. The study shown that environmental policy can reduce pollutant concentration in urban area. Meanwhile, adding density has changed the relationship between population and PM become linear. Implying, large urban area in England and Wales are not more efficient than small ones in terms of PM concentration

In second regression, major town and cities has been used as unit analysis. From this regression, population and density significantly influence CO2 emission. Again, this finding confirm the result from previous study about the relationship between population, density and CO2 emission (Fragkias, Lobo, et al., 2013, Lee and Lee, 2014, Oliveira, Andrade Jr, et al., 2014, Louf and Barthelemy, 2014b, Mohajeri, Gudmundsson, et al., 2015, Gudipudi, Fluschnik, et al., 2016). Linear relationship also found in this regression, similar with first regression using urban LAD as unit analysis. Meaning that large major town and cities are not more environmentally friendly than small ones. Moreover, significant relationship between density and PM shown that higher density major town and cities have less concentration of CO2 than lower density ones. In addition, sub linear relationship was found when GVA is added to regression model. Meaning that in major town and cities in England and Wales, large cities are more environmentally friendly that small one, showing economies of scale of large cities.

There is no significant difference result between first regression, using urban LAD as unit analysis and second regression, using major town and cities as unit analysis. Both of them shown there is linear relationship between urban size, density and CO2 emission and PM. Indicating, large cities are not more environmentally friendly than small ones. Even though, the first and the second regression use different definition of urban, some of the data which was used in second regression still same due to availability of data. Therefore, there is no significant difference result between them.

Overall, as expected, population and density are significant variables in influencing CO2 emission and PM. This finding confirms importance of population and density as element of urban form in determining environmental performances in urban area. There is linear relationship between population, density, CO2 and PM. It means large urban areas is not more efficient than small ones. However, comparing result from urban LAD and major town and cities, there is no significant difference result. Both of them showing linear relationship between urban size and density CO2 emission and PM. In addition, economic condition of urban area influence concentration of CO2 emission.

This study found that population and density influence CO_2 emission and concentration of PM. The linear relationship between variables shown that CO_2 emission and concentration of PM increase proportionally as population growth in urban area. Further, this finding is important in formulating recommendation in urban area, particularly in developing green cities. In urban planning, need to consider urban form, particularly urban size and density in order to plan environmentally friendly cities to minimize CO_2 emission and concentration of air pollution. As argued by Wang, Huang, et al (2018) that urban form is one of important aspect to consider in planning process.

5.2 Limitation and recommendation for future research

There are some limitation in this study regarding data, method and result. The major limitation of this study is data availability. Data about CO_2 emission in city level is not widely available. Most of the data only available in country level. Thus, study about CO_2 emission in city level is become challenging. Moreover, when the data is available at urban level, most of them use different definition of urban areas, which is administrative boundary. Defining urban area using administrative boundary sometimes not illustrate characteristic and condition of urban areas. Therefore, collecting urban data beyond administrative boundary is important. As will give significant result for future research.

Regarding variable, this study only employed urban size and density as element of urban form to analyse relationship with environmental performance. In fact, there are a lot of element of urban form than can be use. Considering importance of urban form to environmental performance, another study uses another element of urban form will have impact in addition to body of knowledge. Moreover, this study only did statistical analysis without including spatial analysis. The result from spatial analysis will give better understanding about location. Therefore, will be useful to formulate urban policy.

In addition, this study employ data from England and Wales. Thus, the result only can applicable in this scope of study. Another study using different variable in different location will give different result, due to different geographic condition and policy.

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Annex 1: Variables Data Urban LAD

No	Urban LAD	Rural Urban Classification	Total CO2	Per Capita Emissions (t)	Area (sq km)	Population	Density	Total PM 10	Total PM 2.5	Gross Value Added (Income Approach)
			(kt)	(t)	(sq km)	person	(people per sq. km)	(t)	(t)	£ million
1	Darlington	Urban with City and Town	**551,7**	5,2	197	106,0	537	141,13	92,26	2591
2	Gateshead	Urban with Major Conurbation	**1.087,3**	5,4	142	201,7	1.417	215,70	149,89	4354
3	Hartlepool	Urban with City and Town	**479,6**	5,2	94	92,5	989	169,81	104,33	1459
4	Middlesbrough	Urban with City and Town	**676,3**	4,9	54	139,3	2.585	116,23	87,81	2587
5	Newcastle upon Tyne	Urban with Major Conurbation	**1.398,0**	4,8	113	290,8	2.563	216,71	156,42	7683
6	North Tyneside	Urban with Major Conurbation	**942,3**	4,6	82	202,7	2.463	153,57	116,85	4055
7	South Tyneside	Urban with Major Conurbation	**570,1**	3,8	64	148,5	2.306	117,17	80,84	2132
8	Stockton-on-Tees	Urban with City and Town	**2.495,1**	12,8	205	195,1	952	316,00	252,35	3946
9	Sunderland	Urban with Major Conurbation	**1.388,2**	5,0	137	276,8	2.014	459,70	357,26	5745
10	Blackburn with Darwen	Urban with City and Town	**595,7**	4,0	137	147,9	1.079	198,05	156,25	2726
11	Blackpool	Urban with City and Town	**535,3**	3,8	35	140,2	4.022	158,55	130,54	2146
12	Bolton	Urban with Major Conurbation	**1.160,4**	4,1	140	281,8	2.016	410,24	313,16	4721
13	Bury	Urban with Major Conurbation	**752,5**	4,0	99	187,8	1.888	231,61	178,62	3139
14	Halton	Urban with City and Town	**699,0**	5,5	79	126,7	1.602	324,22	274,63	3380
15	Knowsley	Urban with Major Conurbation	**772,8**	5,2	87	147,3	1.702	342,67	271,55	3652
16	Burnley	Urban with City and Town	**376,9**	4,3	111	87,3	788	137,04	113,30	1616
17	Fylde	Urban with City and Town	**431,4**	5,6	166	77,5	467	149,55	108,82	2235
18	Hyndburn	Urban with City and Town	**364,9**	4,6	73	80,1	1.097	197,07	142,34	1283
19	Pendle	Urban with City and Town	**419,7**	4,7	169	89,9	531	183,84	155,42	1432

20	Preston	Urban with City and Town	**611,2**	4,3	142	140,7	989	223,02	175,15	3422
21	Rossendale	Urban with City and Town	**402,5**	5,8	138	69,4	503	153,67	93,79	1185
22	South Ribble	Urban with City and Town	**640,4**	5,8	113	109,7	971	257,10	198,06	2768
23	Liverpool	Urban with Major Conurbation	**1.959,5**	4,1	112	480,9	4.300	536,71	456,05	10907
24	Manchester	Urban with Major Conurbation	**2.204,4**	4,2	116	529,8	4.581	432,02	343,65	17030
25	Oldham	Urban with Major Conurbation	**816,9**	3,5	142	230,2	1.617	251,80	192,08	3569
26	Rochdale	Urban with Major Conurbation	**836,9**	3,9	158	214,3	1.355	285,43	215,21	3345
27	Salford	Urban with Major Conurbation	**1.011,0**	4,1	97	245,2	2.523	278,49	212,10	5780
28	Sefton	Urban with Major Conurbation	**1.146,0**	4,2	155	274,1	1.768	417,21	356,11	4042
29	St. Helens	Urban with Major Conurbation	**875,5**	4,9	136	177,6	1.302	271,23	219,07	2810
30	Stockport	Urban with Major Conurbation	**1.176,4**	4,1	126	288,2	2.286	344,87	268,26	6173
31	Tameside	Urban with Major Conurbation	**813,9**	3,7	103	221,5	2.147	293,57	224,93	3430
32	Trafford	Urban with Major Conurbation	**1.338,0**	5,7	106	233,0	2.197	299,58	242,01	7614
33	Warrington	Urban with City and Town	**1.025,3**	4,9	181	207,8	1.150	680,54	414,84	6505
34	Wigan	Urban with Major Conurbation	**1.270,1**	3,9	188	322,2	1.713	371,58	294,22	4804
35	Wirral	Urban with Major Conurbation	**1.230,3**	3,8	157	321,7	2.048	366,78	303,73	4661
36	Barnsley	Urban with Minor Conurbation	**1.261,8**	5,3	329	239,9	729	442,20	316,54	3499
37	Bradford	Urban with Major Conurbation	**2.258,3**	4,3	366	529,9	1.446	669,96	526,17	9504
38	Calderdale	Urban with Major Conurbation	**1.029,1**	5,0	364	207,8	571	522,50	405,10	4366
39	Doncaster	Urban with Minor Conurbation	**1.600,5**	5,2	568	305,5	538	493,50	333,85	5148
40	Kingston upon Hull, City of	Urban with City and Town	**1.204,4**	4,7	71	258,6	3.619	363,82	293,69	5129
41	Kirklees	Urban with Major Conurbation	**1.854,1**	4,3	409	432,9	1.059	688,01	497,04	7207
42	Leeds	Urban with Major Conurbation	**3.453,6**	4,5	552	773,2	1.401	1105,28	860,00	21260
43	North East Lincolnshire	Urban with City and Town	**1.068,5**	6,7	192	160,0	834	216,27	171,63	3267
44	Rotherham	Urban with Minor Conurbation	**1.283,0**	4,9	287	260,9	911	414,03	308,17	4369
45	Sheffield	Urban with Minor Conurbation	**2.381,9**	4,2	368	569,2	1.547	557,53	431,94	11300
46	Wakefield	Urban with City and Town	**1.836,6**	5,5	339	334,0	986	668,25	436,99	6621

47	York	Urban with City and Town	**921,5**	4,5	272	205,8	757	217,39	162,57	5068
48	Derby	Urban with City and Town	**1.147,8**	4,5	78	253,9	3.254	381,77	308,56	6932
49	Amber Valley	Urban with Minor Conurbation	**699,2**	5,6	265	124,2	468	260,87	203,22	2542
50	Chesterfield	Urban with City and Town	**468,8**	4,5	66	104,5	1.582	123,28	96,66	2150
51	Erewash	Urban with Minor Conurbation	**466,8**	4,1	110	114,7	1.046	191,62	152,61	1830
52	North East Derbyshire	Urban with City and Town	**493,0**	4,9	276	99,7	362	225,38	187,78	1487
53	Leicester	Urban with City and Town	**1.423,0**	4,1	73	344,0	4.691	287,46	228,74	7473
54	Blaby	Urban with City and Town	**456,3**	4,7	130	96,5	739	159,75	117,02	2640
55	Charnwood	Urban with City and Town	**878,9**	5,0	279	175,2	628	319,89	208,72	3220
56	Oadby and Wigston	Urban with City and Town	**206,7**	3,7	24	56,0	2.380	51,53	42,67	890
57	Lincoln	Urban with City and Town	**376,5**	3,9	36	96,6	2.708	97,39	67,11	2398
58	Corby	Urban with City and Town	**498,4**	7,5	80	66,9	833	74,15	57,21	1379
59	Kettering	Urban with City and Town	**638,3**	6,5	233	97,6	418	199,28	152,82	1851
60	Northampton	Urban with City and Town	**971,4**	4,4	81	221,5	2.742	210,34	160,97	5873
61	Nottingham	Urban with Minor Conurbation	**1.271,8**	4,0	75	318,9	4.275	289,11	230,69	8816
62	Ashfield	Urban with City and Town	**615,8**	5,0	110	123,6	1.128	150,27	114,26	2190
63	Broxtowe	Urban with Minor Conurbation	**525,9**	4,7	80	111,8	1.396	137,66	107,29	1983
64	Gedling	Urban with Minor Conurbation	**438,5**	3,8	120	116,1	968	156,87	109,44	1674
65	Mansfield	Urban with City and Town	**467,8**	4,4	77	106,8	1.392	115,03	85,05	1597
66	Birmingham	Urban with Major Conurbation	**4.436,5**	4,0	268	1.113,0	4.156	1070,20	854,49	24790
67	Coventry	Urban with City and Town	**1.409,5**	4,1	99	344,3	3.490	358,99	277,80	7655
68	Dudley	Urban with Major Conurbation	**1.236,3**	3,9	98	316,3	3.229	408,61	314,74	4988
69	Sandwell	Urban with Major Conurbation	**1.427,7**	4,5	86	319,1	3.730	386,05	308,72	5847
70	Solihull	Urban with Major Conurbation	**1.128,9**	5,4	178	210,8	1.183	374,35	290,62	6672
71	Newcastle-under-Lyme	Urban with City and Town	**659,3**	5,2	211	126,9	601	249,90	167,16	1909
72	Tamworth	Urban with City and Town	**305,8**	4,0	31	77,1	2.499	142,64	100,38	1290
73	Stoke-on-Trent	Urban with City and Town	**1.412,1**	5,6	93	251,7	2.694	310,57	239,87	4763

74	Telford and Wrekin	Urban with City and Town	**938,9**	5,5	290	171,7	591	326,32	209,30	3633
75	Walsall	Urban with Major Conurbation	**1.069,5**	3,9	104	275,9	2.653	386,91	277,11	4765
76	Nuneaton and Bedworth	Urban with City and Town	**517,5**	4,1	79	126,6	1.604	181,56	137,75	2000
77	Rugby	Urban with City and Town	**680,2**	6,5	351	104,5	297	220,72	149,67	2222
78	Warwick	Urban with City and Town	**763,7**	5,5	283	138,9	491	216,10	165,87	4710
79	Wolverhampton	Urban with Major Conurbation	**1.078,0**	4,2	69	255,1	3.674	266,04	218,01	4625
80	Bromsgrove	Urban with City and Town	**444,3**	4,6	217	95,8	442	195,31	134,81	1918
81	Redditch	Urban with City and Town	**356,4**	4,2	54	84,8	1.563	93,77	67,63	1770
82	Worcester	Urban with City and Town	**398,2**	3,9	33	101,0	3.035	106,21	83,26	2544
83	Cambridge	Urban with City and Town	**592,8**	4,7	41	125,1	3.074	99,64	77,41	5917
84	Basildon	Urban with City and Town	**821,7**	4,5	110	182,0	1.654	224,52	169,84	4481
85	Castle Point	Urban with City and Town	**312,6**	3,5	45	89,2	1.979	87,97	72,41	1295
86	Chelmsford	Urban with City and Town	**922,0**	5,3	339	172,7	510	323,28	239,76	4342
87	Harlow	Urban with City and Town	**402,6**	4,7	31	85,3	2.794	79,49	60,18	1937
88	Rochford	Urban with City and Town	85,2	4,6	169	3,8	503	144,65	97,81	1423
89	Broxbourne	Urban with Major Conurbation	**429,8**	4,5	51	96,3	1.872	95,02	73,89	2249
90	Hertsmere	Urban with Major Conurbation	**524,0**	5,1	101	103,2	1.020	140,29	111,32	3252
91	St Albans	Urban with City and Town	**619,1**	4,2	161	146,2	907	209,44	158,46	4251
92	Stevenage	Urban with City and Town	**385,5**	4,5	26	86,6	3.334	95,22	65,63	2406
93	Three Rivers	Urban with Major Conurbation	**384,4**	4,2	89	91,8	1.033	119,92	91,06	3005
94	Watford	Urban with Major Conurbation	**398,5**	4,1	21	96,3	4.496	80,66	63,95	3836
95	Welwyn Hatfield	Urban with City and Town	**581,7**	4,9	130	117,8	909	191,72	151,47	3791
96	Luton	Urban with City and Town	**722,1**	3,4	43	213,6	4.927	197,94	164,96	4888
97	Norwich	Urban with City and Town	**587,4**	4,3	39	138,1	3.539	133,20	109,61	3907
98	Peterborough	Urban with City and Town	**1.050,6**	5,4	343	193,7	564	340,62	221,20	5382
99	Southend-on-Sea	Urban with City and Town	**620,4**	3,5	42	179,2	4.292	134,44	109,31	3132
100	Ipswich	Urban with City and Town	**470,5**	3,4	40	137,7	3.484	168,41	142,24	3345

101	Thurrock	Urban with Major Conurbation	**904,9**	5,4	163	166,0	1.016	293,73	213,41	3270
102	London	Urban with Major Conurbation	33.042,0	#REF!	1.571,0	8.666,9	240.551,0	5.329,7	4.087,9	378.424,0
103	Bracknell Forest	Urban with City and Town	**491,1**	4,1	109	119,2	1.090	177,26	148,50	3818
104	Brighton and Hove	Urban with City and Town	**1.014,9**	3,6	83	284,1	3.431	308,63	258,48	7129
105	Eastbourne	Urban with City and Town	**352,6**	3,5	44	102,2	2.314	126,22	109,64	1869
106	Hastings	Urban with City and Town	**352,6**	3,5	30	102,2	3.093	119,89	103,00	1625
107	Eastleigh	Urban with City and Town	**481,3**	3,7	80	129,0	1.617	262,33	212,39	3595
108	Fareham	Urban with City and Town	**419,0**	3,6	74	115,2	1.551	231,89	194,05	2741
109	Gosport	Urban with City and Town	**251,2**	3,0	25	84,8	3.342	111,21	96,10	1153
110	Havant	Urban with City and Town	**451,2**	3,7	55	123,1	2.223	225,54	192,62	2641
111	Rushmoor	Urban with City and Town	**397,6**	4,2	39	95,2	2.437	126,28	105,53	3101
112	Canterbury	Urban with City and Town	**684,4**	4,3	309	159,7	517	265,47	213,71	3050
113	Dartford	Urban with Major Conurbation	**513,8**	5,0	73	103,5	1.423	193,33	155,88	3064
114	Gravesham	Urban with Major Conurbation	**506,6**	4,8	99	105,7	1.068	161,41	137,04	1603
115	Thanet	Urban with City and Town	**538,2**	3,8	103	139,8	1.353	206,08	173,89	2099
116	Medway	Urban with City and Town	**912,8**	3,3	194	275,2	1.422	477,18	406,00	4794
117	Milton Keynes	Urban with City and Town	**1.295,4**	4,9	309	263,2	853	441,54	362,99	10884
118	Oxford	Urban with City and Town	**757,4**	4,9	46	154,7	3.393	226,75	193,05	6549
119	Portsmouth	Urban with City and Town	**821,3**	3,9	40	210,5	5.212	358,61	286,12	5344
120	Reading	Urban with City and Town	**609,4**	3,8	40	161,7	4.003	208,94	169,37	6679
121	Slough	Urban with City and Town	**689,5**	4,7	33	146,0	4.488	211,65	157,14	6528
122	Southampton	Urban with City and Town	**870,4**	3,5	50	246,1	4.930	325,49	280,68	5873
123	Elmbridge	Urban with Major Conurbation	**677,2**	5,0	95	135,4	1.424	221,94	183,92	4446
124	Epsom and Ewell	Urban with Major Conurbation	**282,0**	3,6	34	78,5	2.302	102,19	88,66	2035
125	Guildford	Urban with City and Town	**849,4**	5,9	271	145,1	535	264,70	216,94	5283
126	Reigate and Banstead	Urban with City and Town	**655,4**	4,6	129	143,8	1.113	232,62	193,75	4754
127	Runnymede	Urban with Major Conurbation	**415,7**	4,9	78	85,0	1.089	165,74	131,84	3894

128	Spelthorne	Urban with Major Conurbation	**392,2**	4,0	45	98,4	2.193	160,50	128,00	2721
129	Surrey Heath	Urban with City and Town	**460,5**	5,2	95	88,4	929	198,29	166,42	3298
130	Woking	Urban with Major Conurbation	**464,7**	4,6	64	101,0	1.588	151,32	128,08	3562
131	Adur	Urban with City and Town	**254,7**	4,0	42	63,5	1.515	111,59	94,91	1157
132	Arun	Urban with City and Town	**634,5**	4,1	221	155,8	705	287,72	240,64	2489
133	Crawley	Urban with City and Town	**559,0**	5,0	45	110,9	2.466	170,89	144,29	4759
134	Mid Sussex	Urban with City and Town	**739,8**	5,1	334	146,0	437	339,84	256,23	3544
135	Worthing	Urban with City and Town	**382,3**	3,5	33	108,3	3.330	144,99	124,14	2566
136	Windsor and Maidenhead	Urban with City and Town	**741,0**	5,0	197	148,3	755	290,21	229,70	5851
137	Wokingham	Urban with City and Town	**668,2**	4,1	179	161,2	901	319,37	248,19	5834
138	Bournemouth	Urban with City and Town	**662,2**	3,5	46	191,7	4.151	184,50	153,70	4255
139	Bristol, City of	Urban with City and Town	**1.675,8**	3,7	110	450,6	4.108	497,90	403,13	13862
140	Exeter	Urban with City and Town	**539,0**	4,3	47	125,7	2.672	183,20	147,65	4085
141	Christchurch	Urban with City and Town	**230,0**	4,7	50	49,2	977	76,83	61,98	1081
142	Weymouth and Portland	Urban with City and Town	**232,7**	3,6	42	65,2	1.561	106,40	68,56	933
143	Cheltenham	Urban with City and Town	**465,9**	4,0	47	116,6	2.502	149,24	120,69	3241
144	Gloucester	Urban with City and Town	**510,6**	4,0	41	127,2	3.136	176,84	152,70	3422
145	Plymouth	Urban with City and Town	**1.009,8**	3,9	80	261,4	3.274	415,83	328,23	5192
146	Poole	Urban with City and Town	**666,5**	4,4	65	150,0	2.316	251,11	206,45	3954
147	South Gloucestershire	Urban with City and Town	**1.306,8**	4,8	497	274,0	551	654,24	459,01	8674
148	Swindon	Urban with City and Town	**1.063,2**	4,9	230	217,6	946	380,41	300,33	6682
149	Torbay	Urban with City and Town	**477,5**	3,6	63	133,8	2.127	197,66	170,74	2081
150	Blaenau Gwent	Urban	**309,5**	4,5	109	69,5	640	128,17	105,91	764
151	Bridgend	Urban	**710,7**	5,0	251	142,3	567	377,67	321,47	2779
152	Caerphilly	Urban	**814,4**	4,5	277	180,2	650	352,44	274,03	2417
153	Cardiff	Urban	**1.681,5**	4,7	141	357,5	2.537	545,13	425,17	9016
154	Conwy	Urban	**604,5**	5,2	1.126	116,5	103	243,80	197,18	1809

155	Flintshire	Urban	**1.182,3**	7,7	437	154,1	352	1036,70	863,88	3644
156	Merthyr Tydfil	Urban	**269,5**	4,5	111	59,2	532	105,08	82,17	915
157	Neath Port Talbot	Urban	**1.022,7**	7,3	441	140,9	319	2367,14	1595,71	2142
158	Newport	Urban	**890,0**	6,0	191	148,0	777	300,90	224,79	3081
159	Rhondda Cynon Taf	Urban	**1.070,6**	4,5	424	237,4	560	457,02	380,61	3663
160	Swansea	Urban	**1.075,4**	4,4	380	242,3	638	368,22	306,02	4503
161	Torfaen	Urban	**469,5**	5,1	126	91,8	730	213,47	181,94	1492
162	Vale of Glamorgan	Urban	**617,1**	4,8	331	128,0	387	571,10	343,60	2028
163	Wrexham	Urban	**1.000,8**	7,4	504	135,4	269	1033,16	864,82	2553

Annex 2: Variables Data Major Town and Cities

No	Major Town and Cities	Population	Density	Total CO2	CO2 per capita	Total PM 10	Total PM 2.5	GVA
		person	(people per sq. km)	(kt)	(t)	(t)	(t)	£ million
1	Liverpool	480873	3899,63	1959,5	4,1	619,03	613,49	10907
2	Southampton	246054	4595,92	870,4	3,5	381,32	380,33	5873
3	Leicester	344036	4392,84	1423	4,1	296,99	294,94	7473
4	Kingston upon Hull	258587	3511,85	1204,4	4,7	357,06	347,11	5129
5	Bristol	450640	4007,11	1675,8	3,7	573,2	563,28	13862
6	Blackpool	140162	4066,2	535,3	3,8	161,09	161,09	2146
7	Luton	213581	5241,9	722,1	3,4	193,64	188,11	4888
8	Ipswich	137694	3727,25	470,5	3,4	165,39	164,24	3345
9	Cambridge	125105	3325,05	592,8	4,7	125,61	125,06	5917
10	Middlesbrough	139310	2842,34	676,3	4,9	131,89	131,52	2587
11	Bournemouth	191673	4761,18	662,2	3,5	175,36	175,23	4255
12	Southend-on-Sea	179234	4958,07	620,4	3,5	138,54	137,83	3132
13	Birmingham	1112950	4857,18	4436,5	4	1027,28	1004,96	24790
14	Wolverhampton	255106	4300,14	1078	4,2	214,41	212,61	4625
15	Gloucester	127169	3681,78	510,6	4	160,67	159,82	3422
16	Manchester	529809	5440,21	2204,4	4,2	416,9	414,09	17030
17	Nottingham	318936	5102,77	1271,8	4	237,57	235,34	8816
18	Slough	146038	5393,82	689,5	4,7	193,01	188,37	6528
19	Stevenage	86579	4022,72	385,5	4,5	84,28	84,28	2406
20	Portsmouth	210538	6360,66	821,3	3,9	341,64	340,06	5344
21	Stoke-on-Trent	251746	3312,55	1412,1	5,6	277,21	273,17	4763
22	London	8666930	6974,09	33042	3,81	4872,69	4767,72	378424
23	Lincoln	96641	3515,5	376,5	3,9	77,26	75,67	2398
24	Worthing	108303	4405,7	382,3	3,5	141,82	141,43	2566
25	Derby	253875	4324,96	1147,8	4,5	332,3	257,79	6932
26	Plymouth	261386	4376,12	1009,8	3,9	353,02	345,24	5192
27	Coventry	344288	4679,26	1409,5	4,1	305,48	274,71	7655
28	Worcester	100985	4167,34	398,2	3,9	83,74	82,41	2544
29	Oxford	154716	4733,19	757,4	4,9	193,01	153,24	6549
30	Poole	150005	3240,02	666,5	4,4	225,54	222,28	3954
31	Hastings	91937	4343,82	352,6	3,5	107,75	107,61	1625
32	Northampton	221503	3905,37	971,4	4,4	174,27	172,98	5873

Annex 3: IHS copyright form

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