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Measuring environmental performance of smart cities in Scotland

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Summary

The issue of rising greenhouse gas emissions has been occurring within large megacities across China as well as, New York, Tokyo and London. As urbanization has occurred at such a rapid pace around the world, human settlements have now become one of the major contributors to greenhouse gas emissions, and in particular metropolitan regions, are the hotspots for human activities and the main sources of greenhouse gas emissions (Minx *et al.*, 2013). Environmental degradation in cities has long been an issue that both the public and private sectors have had to address.

The invention and evolution of technology is something that has changed the way the humans live, work and play. It has changed almost every facet of our lives and plays an enormous role in shaping the way we interact with each other, but it has also changed the way we interact with the city we live in. The concept of a 'smart city' is a relatively new phenomena that has taken over the world in the past 20 years. Everyone from academic researchers and city governments to the business and tech elite have started coming up with new ways in which information communication technology (ICT) and big data can be utilized to help the city progress and become more efficient. Although a large body of work has been compiled on smart cities, there still lacks an overall definition of what a smart city is. Smart cities are those that are designed to help improve the efficiency and equity of cities without reducing the economic output.

While the smart cities discourse has focused on a typology of the concept and comparison of city level plans, little empirical work has been conducted on the environmental performance of smart cities. This study seeks to bridge that gap by exploring if smart city planning has had an impact of the environmental performance in terms of CO_2 emissions of cities in Scotland from 2005 – 2016. This empirical research takes a combination of the largest authors contributions to smart cities research to create four pillars that represent the smart city and runs a spatial and statistical analysis on the data to see if there is a clustering of CO_2 emissions and if smart city planning can have an impact on reducing emissions. Correlation analysis, Getis Ord hotspot analysis, Moran's I, panel models and spatial panel models are conducted to explore the relationships.

The study finds that CO_2 emissions are clustered along the densely populated corridor between Glasgow and Edinburgh. This is likely attributed to the large amount of industry that occurs in the area as shown in the Getis Ord hot spot analysis. Statistically the results of the regression analysis show that with no spatial component included in the regression there is a very low likelihood that smart cities have impacted the reduction in CO_2 emissions from 2005 to 2016. When the spatial component is included the impact that both technology, connectivity and specifically the presence of a smart agenda as smart city planning has on CO_2 emissions is much stronger.

Keywords

CO_2 Emissions, Smart City, Spatial Panel Data, GIS, R

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Abbreviations

IHS	Institute for Housing and Urban Development
ICT	Information communication technology
FDI	Foreign direct investment
GHG	Green House Gas
UK	United Kingdom
OECD	Organization for Economic Co-operation and Development
UN	United Nations
CO_2	Carbon Dioxide
LAD	Local Authority District
LULUCF	Land Use, Land Use Change and Forestry

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Background

Over the last two decades, cities around the world have emerged as the leading sources of the world's economic production, innovation, and trade (*World Cities Report 2016*, 2016). More than half the world's population is living in urbanized areas, and this figure is set to rise, with projections as high as two thirds of the world's population by 2050 (UN Development Programme, 2016). Urbanization is occurring around the world at an alarming rate and with these cities are experiencing new socio-economic and environmental issues that had not existed decades ago. Many aspects of this urban change has bene so rapid that they have overwhelmed government and business capacity to manage it, with new programs being setup almost annually to tackle new issues (Revi *et al.*, 2014). The United Nations Development Programme has outlined seventeen sustainable development goals, with the aim of producing a set of universal objectives that meet the urgent environmental, political and economic challenges currently facing our world (UN Development Programme, 2016). As one of the largest overarching plans for future sustainable development, these goals are concerned with ensuring the world remains a safe and habitable place for our future generations and places cities are the forefront of this change (UN Development Programme, 2016). While overlooked by many other global plans, at the heart of these goals lies the need to retrofit cities to become more resilient to climate change and ensure the world is habitable for future generations to come.

In October of 2013, the United Kingdom published its research on smart cities, outlining both the challenges cities are facing today and tomorrow and the role smart cities can play in strengthening the United Kingdom. The UK government defines a smart city as a city that "brings together hard infrastructure, social capital including local skills and community institutions, and digital technologies to fuel sustainable economic development and provide an attractive environment for all" (Department for Business Innovation & Skills, 2013, p. 7). Central to the motivations behind the research are the diverse range of challenges that are driving change within cities across the United Kingdom. These include, rising urban populations and the need for adequate infrastructure to service these cities, economic restructuring combined with the looming threat of BREXIT, uncertainty and economic downturn has raised levels of unemployment throughout the country (Department for Business Innovation & Skills, 2013). The Scottish Government released the Smart Cities Scotland Blueprint 2016, outlining the future plans for Scotland and their movement towards a more inclusive and connected country. At a high level, this Scottish Cities Alliance aims to achieve four goals, engaging and empowering citizens and communities, create a healthy, innovative and resourceful place to live, transform Scotland into a smart and sustainable country and finally improve city performance (Urban Foresight, 2016). To achieve these goals, a city coalition has been formed between the seven cities within Scotland to work together in delivering these objectives. The idea of a smart city is not a static concept, no definitive model has been agreed upon, and it cannot be seen as a one shoe fits all methodology. Nonetheless, it is understood that the smart city can be utilized to help mitigate the issues mentioned above. With this in mind, Scotland has concluded that there are six key aspects to smarter approaches for cities. These include the use of open data, citizen centric service delivery, the use of intelligent infrastructure, openness to learn from others and experiment with new business approaches, greater transparency and finally clear and consistent leadership (Department for Business Innovation & Skills, 2013).

The United Kingdom has identified this development and while it understands that the majority of the development will occur outside of the UK, it would be an oversight to believe that smart urban development is strictly a developing world phenomenon. There is a wide range of services that cities can utilize to improve the efficiency, equity environmental sustainability and quality of life of urban regions. In addition to the smart cities background paper the UK and EU governments have enacted a wide range of programmes to enhance locational competitiveness, promote sustainability and attract new business and talent. The UK smart cities whitepaper depicts the strong motivation the UK has for promoting smart city approaches to increase sustainability, reduce emissions, increase global competitiveness and increase equity and quality of live throughout its member countries which sets the stage for this study.

The purpose of this research is to contribute to the empirical body of research on smart cities in terms of sustainable performance measurement. This paper will take fourteen local authority districts throughout Scotland, all with varying levels of smartness and determine if by creating a smarter city helps contribute to a reduction in greenhouse gas emissions (GHG) which will be specifically measured in terms of CO_2 emissions. By combining the frameworks established by the leading research on smart cities, a classification method of a smart city is proposed by utilizing the six axes framework of the smart governance, connectivity, hard infrastructure and smart transportation to act as proxies of city smartness. The data for this project will be drawn exclusively from a number of governmental agencies involved in collecting statistical data within the United Kingdom as well as third party individual sources. These will then be tested through both spatial and panel series analysis in which cities throughout Scotland will be analysed to determine if smart cites help in reducing CO_2 emissions.

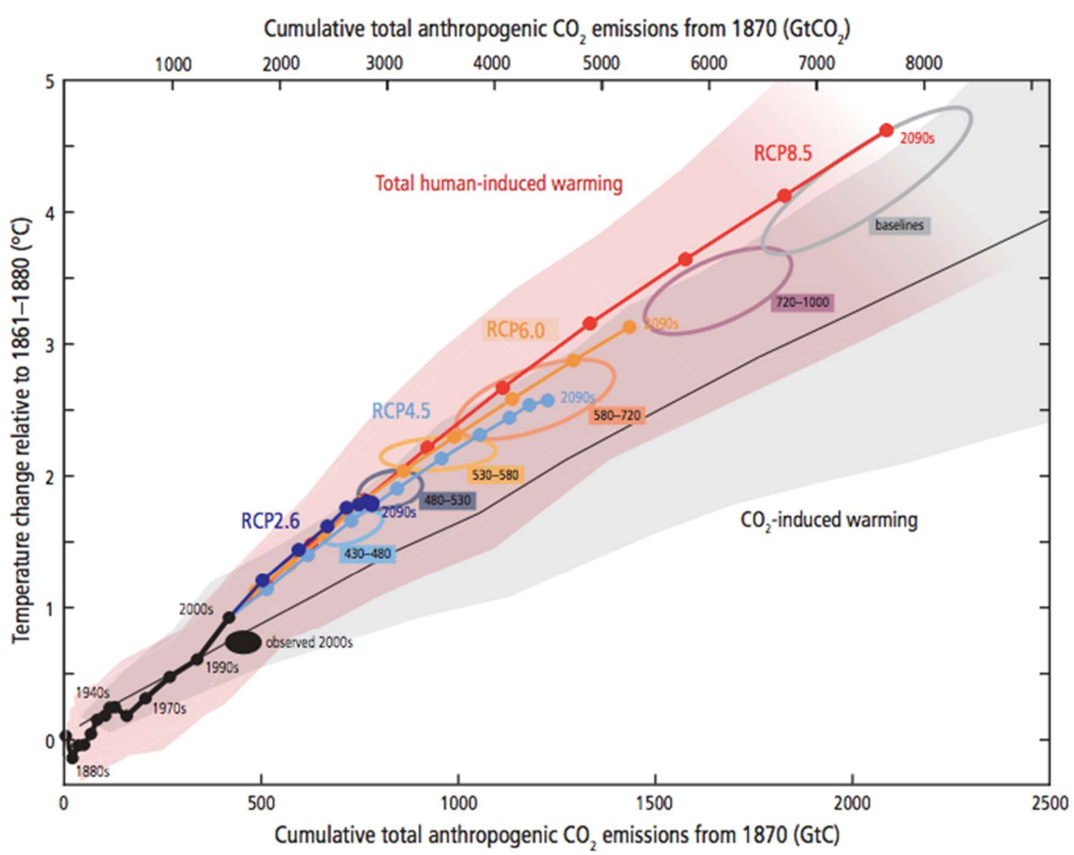
1.2 Research Problem

How cities cope with evolving city dynamics needs to be revaluated, as contemporary urban issues are not readily solved with yesterday's solutions. To effectively address these issues, researchers, business and governments alike will need to produce innovative ways to explain and solve these problems (Chourabi *et al.*, 2012). While the tendencies of urban professionals have traditionally been to approach the problems of a city in a tantamount fashion, the increasing level of complexity of city planning that has emerged in the past three decades calls for updated methodologies. As mentioned prior, city planning is no longer solely concerned with the built form aesthetics and economic competitiveness of a city, but consideration must be placed on climate change and sustainability issues as well. Climate change is one of the most pressing issues facing our world today and cities play a crucial role in helping to eradicate these issues (Revi *et al.*, 2014).

As the world continues to urbanize and cluster within urban centres, a number of previously non-existent negative externalities have emerged. The leading one being climate change and an increase in greenhouse gas emissions. This can be attributed to rising household consumption and industrial production, both of which are related to the burning of fossil fuels (OECD, 2010). Cities play an increasing role in the contribution to GHG and with this have a crucial role to play in the stabilization and reduction of these GHG. Particularly in CO_2 emissions which is one of the leading manmade GHG's. Urban areas hold approximately more than half of the world's population and most of the economic activity meaning that the hold not only produce the majority of the worlds GHG emissions but they have the ability to mitigate it as well (Revi *et al.*, 2014). While this is the case the risk of rising temperatures and sea levels is an important issue effecting the earth and in turn all those that inhabit it. Working to mitigate these problems is an extremely important issue that must be solved.

Figure 1 shows the global mean surface temperature rising on a linear trend with a rise in anthropogenic CO_2 emissions. With the multi-model results from the Representative Concentration Pathways to 2100 are shown with coloured lines, with historical time series data shown in black (1880 – 2010). The graph shows the projected rise in surface temperature based on a different estimate of CO_2 levels. As seen, to keep the rise in temperature to within 2 °C then RCP2.6 will be the required achievement with cumulative total anthropogenic CO_2 emissions from 1870 ($GtCO_2$) to be around 2700 and (GtC) to be around 700. To successfully achieve this by 2100 a number of changes within society will need to be updated and altered to reflect a more sustainable future.

Figure 1: Temperature projections based on multi-model future CO_2 emissions pathways 1870-2100



Source: (Pachauri *et al.*, 2014)

Within the United Kingdom a number of national and local initiatives have been enacted to help mitigate climate change. The foremost one being the Climate Change Act of 2008 which set the stage to the United Kingdom taking large strides to move towards a more sustainable future (Parliament of the United Kingdom, 2008). Over the years, it became more evident that not only households and industries play a large part of climate change but cities and urban agglomerations are vital parts of the fight to impede climate change (OECD, 2010).

The use of technology has the potential to play a significant role in helping to reduce emissions. Smart city approaches as a means for sustainable urban development is an incredibly new but widely seen as one of the next best urban planning techniques to help improve the quality of life within cities. Just as these cities contribute to climate change in certain ways they are also vulnerable to climate change impacts (OECD, 2010). While the majority of the impacts from climate change are relatively easily traced such as glacier erosion and rising sea levels, others such as extreme natural disasters are not. Pertaining to the worlds cities, many impacts will vary based on the contextual setting (OECD, 2010).

The complex nature of cities and urban regions calls for innovative ways of solving the issues they face, as each one differs from city to city and region to region. There is no one size fits all approach that can be utilized around the world to mitigate climate change, context plays a large role in this. A growing body of work over the past two decades known as the smart city has been embedding itself as a new technique, cities should adopt in order to achieve the desired outcomes of a higher quality of life for its citizens. At its core, this phenomenon is meant to utilize modern day information communication technology (ICT) in the urban setting while collecting large amounts of data which can then be cleaned and analyzed to influence policy and urban development. Consistently, cities are approaching these issues by utilizing new information communication technologies paired with big data to help explain and solve these modern challenges (Batty *et al.*, 2012). The introduction of these characteristics in an urban setting is what is known as a smart city, and today cities around the world are adopting these techniques. While this is an oversimplified description of what a smart city is, it is a rather quite complicated topic. Over the years a number of top research from the globes leading universities as well as major multinational corporations have begun studying the topic of smart cities and yet there is no agreed upon definition of what a smart city actually is. These range from the environmental, humanistic and business views ranging from

From the early stages of planning from Haussmann's top down approach of the reconstruction of Paris in the early 1850's, the Garden City Movement by Ebenezer Howard to The Radiant City by Charles-Edouard Jeanneret (Le Corbusier), cities today are continuously adopting a more sustainable approach to planning (Hall, 1988). Shmelev and Shmeleva (2009) refer to a sustainable city as a holistic approach to urban planning in which the urban system is seen from a complex perspective in which a multitude of determinants are harmoniously integrated (Shmelev and Shmeleva, 2009). Today cities are migrating towards a more contemporary technique of planning by using new technology and big data to help connect the city, increasing quality of life, city performance and equity amongst its citizens (Giffinger, 2007). A direct link exists between the more contemporary planning ideologies of sustainable and smart cities and their predecessors. While these new methodologies are introducing modern techniques necessary to solve these contemporary issues, they are not without their roots within the traditional methods of urban planning and require adaptation and innovation in order to tackle the contemporary socio-economic issues cities are facing.

An issue encountered is that the majority of research to date has been focused on determining a framework or definition of smart cities, but little has been conducted on the true outcomes of smart cities in terms of sustainable measurement. Diminutive research has been conducted to determine if what is coined as a smart city has an impact on the reduction of greenhouse gas emissions. At its core a smart city aims to reduce the inequality within cities and create a more livable city with a higher quality of life through the use of ICT (Caragliu, del Bo and Nijkamp, 2011). The most common definition of sustainability concerns meeting the needs of today without sacrificing the needs of tomorrow. A smart sustainable city aims to achieve sustainable development within city planning through the use of ICT and smart city policy. While smart cities intend to achieve sustainable development, Bibri and Krosgstie (2017) have identified nineteen research gaps in the field of smart sustainable cities with one of which directly confirming the need for greater work surrounding cities and climate change. "There is no assessment framework for measuring how smartness enhances sustainability and vice versa" (Bibri and Krogstie, 2017, p. 203). Drawing from the understanding that climate change and GHG emissions are a crucial issue that cities must address, this paper seeks to achieve a performance measurement technique to determine if smart city planning has had an impact on the levels of CO_2 emissions throughout the UK and to predict if the increase/decrease in smart city attributes has a decrease/increase on CO_2 emissions.

1.3 Research Objectives

Despite heavy criticism of smart city planning as relevant urban development technique, there is a general understanding that we require new processes to ensure sustainable urban development (Hollands, 2008; Angelidou, 2017). The consequences from globalisation and the localised effects of rapid population growth are putting a beginning to place a strain on cities around the world. Finding and utilizing new innovative management and technical approaches to urban planning are required to mitigate these effects and ensure that development is achieved in a sustainable way.

Recognizing the need for empirical work on the environmental performance of smart cities, this paper aims to identify the key determinants and spatial distribution of CO_2 emissions throughout Scotland as well as analyse the main characteristics of smart cities to determine if by implementing smart city agenda into a city's agenda has helped to reduce the per capita CO_2 emissions of the city. This study will be concentrated on the 15 cities within Scotland, defined as Local Authority Districts LAD. These cities range in geographic and population size as well as varying levels of CO_2 emissions per capita and smartness levels.

Considering the unique nature of smart cities and there being no definitive answer to what a smart city is, a combination of four frameworks will be utilized. For this research a smart city comprises a city that has adequate transport for citizens, economic innovation, integration of ICT into the city, and smart governance (Giffinger, 2007; Batty *et al.*, 2012; Wall and Stavropoulos, 2016).

Conclusion can then be drawn on the environmental performance measurement techniques of smart cities and have a deeper understanding of smart cities contributions to local authority's sustainability achievements. Empirically investigating the sustainability achievements of smart cities is important and beneficial to both local governments and small and large businesses alike. Through finding new be able to have a better understanding of what attributes of smart city planning if any are contributing to reducing CO_2 emissions and therefore the sustainability of the city and our earth. In addition to this, it provides evidence on whether this style of planning contributes to the various sustainability agendas of local authorities within Scotland. While these concepts are very broad in nature, a number of indicators will be set for smart cities and to determine the contributions to local sustainable development. For the purposes of this study this will be set as CO_2 emissions. Therefore, the specific objectives of this paper are to examine the various characteristics of smart cities, explore the key determinants of CO_2 emissions within Scotland and to finally test through both panel and spatial panel regressions to determine if smart city attributes can reduce CO_2 emissions and if they are spatially correlated.

1.4 Research Questions

While a large portion of research has been conducted on a typology of smart cities, diminutive empirical research in relation of environmental and sustainability performance measurement of smart cities. To further analyse the sustainable potentials that smart cities hold the main research question is as follows.

"Has the implementation of smart cities concepts into the urban planning framework contributed to a reduction of **CO_2** ***emissions in Scotland?"***

Three sub questions are required to answer this question.

To help us understand the origins of anthropogenic greenhouse gases in Scotland "*What is the spatial distribution of CO_2 emissions throughout Scotland?"*

Since there is not a clear answer as to what a smart city is in regard to sustainability, air quality and CO_2 emissions, the second sub question will be "*What are the main features of a smart city and are these correlated with* CO_2 *emissions?"*

To determine whether smart cities help to improve the quality of life within cities the final sub question will be "*Can implementing a smart city agenda influence the emissions and air quality of Scottish cities?"*

1.5 Significance of the Study

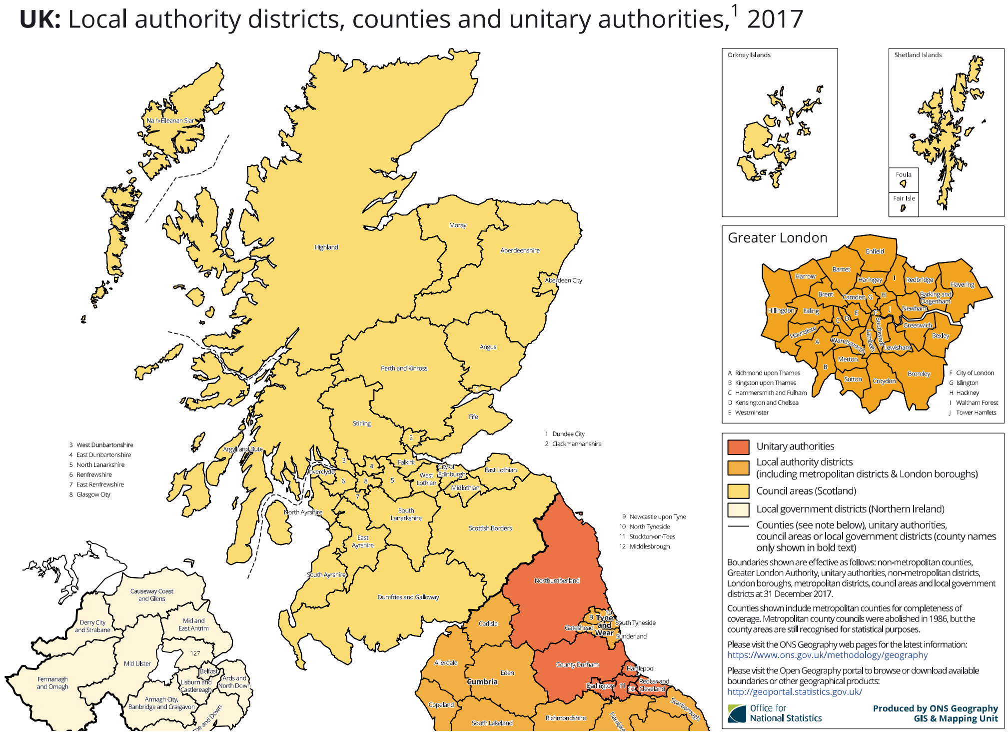
This research will have both scientific and policy relevance by contributing to the discussion on smart cities as well as, contributing to governments policy formation on determining the proper ways to implement, monitor and evaluate smart city initiatives. In addition, this paper will provide insight into a new understanding of urban problems and the new solutions that will shape the future of both environmental management within cities and smart city planning. Scientifically this study will contribute to the call for more empirical work on smart cities performance.

The findings of this study can be utilized by local governments within Scotland by aiding them with clear understanding of the impacts that smart city planning can have on furthering the sustainability of a city. In addition to this, by shedding a light on which aspects of a smart city play the largest role in GHG reductions are crucial for smart cities for policy formation.

1.6 Scope and Limitations

The study will be conducted in 14 local authority districts throughout Scotland. Spatially, the research is spread across the country, with all major cities being included. The extensive amount and detailed nature of the National Statistics Bureaus dataset provides a wealth of evidence regarding regional economic development and smart city attributes Nonetheless, there remain some challenges for analysis and data collection. Secondary datasets limit the number of predictors available, while the population size, limits the sample study to a subset of the intended region. These factors limit the extent to which causal relationships can be inferred and become natural extensions for future research.

Figure 2: Local Authority Districts within Scotland



Source: (Thames *et al.*, 2018)

It is understood that cities are extremely complex and while this study helps to provide an insightful look into the underpinnings of smart cities and city sustainability it does not cover the entire picture. There is a broad range of different externalities that effect cities on both a localized and global scale. Furthermore, urban planning and economic geography is an extremely contextual field of work. What might work for one city or region does not necessarily work for the next one. Policy and research must keep this present as coming to general conclusions does not provide a one answer fits all motif.

Chapter 2: Theoretical Background

This chapter elaborates on the theoretical concepts behind the research as well as provides real world context with empirical examples. The various dimensions discussed in this section range from smart cities, climate change and CO_2 emissions as well as, empirical examples of planning practices and smart cities from around the world.

To begin, a background of the intersection between the city and the environment will be explored. Following this, will be a review of similar studies conducted on both cities and CO_2 emissions as well as, urban planning and environmental documents and policies within the United Kingdom and Scotland. The contextual relationship between cities and the environment will be drawn in this section as well as, the origins and impacts climate change. This will be followed by an examination of smart cities with a theoretical review of the concept as well as, providing the empirical context of today's research. All key authors, theories, intellectual origins, possible definitions of the topic will be covered. In addition to this the major issues, debates and further research opportunities will be explored. As this topic is relatively modern and little empirical research has been conducted to date, it is crucial to provide insight into where the trends and future planning in the field moving towards in the coming years.

2.1 Cities and the Environment

Environmental degradation in cities has long been an issue that both the public and private sectors have had to address. Numerous studies have explored the relationship between cities and climate change to further understand the impacts that cities have on the climate and vice versa. The OECD (2010) recently conducted a study to uncover the intersection of cities and climate change exploring this relationship between the two. This research looks at cities as a central piece within the climate policy challenge that exists, as they are home to the majority of the global energy use and in turn a large source of emissions (OECD, 2010). Roughly half of the world's population lives in urban regions, which in turn use a significant proportion of the worlds energy supply and correlated emissions (OECD, 2010). How urban regions grow and operate plays a large role in energy supply and demand and greenhouse gas emissions. The related emissions to energy use is dictated by the requirements to operate the city and the buildings within the city. Urban density and the economic function of the city plays a large role in dictating the energy required run the city and resulting emissions (OECD, 2010). Whether or not the city is a large metropolis with large industrial regions and a dense urban core, or it is a sprawled region with competing land uses and mixed industries will dictate the levels of energy consumed and the coinciding emissions. While the consumption built form is an important factor, energy sources and technology are becoming an important factor (OECD, 2010). From where the energy is produced, and how it is transported and consumed is an important factor in the emissions output of cities. As new technologies are created new efficiencies are found and emission reductions can be materialized. Urban areas relying on archaic and inefficient energy production methods to fuel the city, will contribute more greenhouse gas emissions than those that consume the same amount of energy from new, efficient production methods (OECD, 2010). As such, new technologies and processes can greatly improve the production and consumption patterns of an urban region. The OECD (2010) has concluded that is not necessarily only cities nor urbanization that can be seen as the sole contributor to greenhouse gas emissions, conversely the way in which transport, growth patterns and sprawl, energy use from industries to homes and building efficiencies make these urban regions the polluters they are (OECD, 2010).

The issue of rising greenhouse gas emissions has been occurring within large megacities across China as well as, New York, Tokyo and London. As urbanization has occurred at such a rapid pace around the world, human settlements have now become one of the major contributors to greenhouse gas emissions, and in particular metropolitan regions, are the hotspots for human activities and the main sources of greenhouse gas emissions (Minx *et al.*, 2013). A major issue that cities, governments and NGO's have faced over the years is how to account for and mitigate these emissions being created (Minx *et al.*, 2013). A study conducted by Jan Minx et al (2013) of the Potsdam Institute for Climate Impact Research of Potsdam Germany covered 434 municipalities within the United Kingdom to determine if carbon footprints were larger than those from rural to highly urbanized areas. While still a relatively unexplored hypothesis, Minx et al was able to determine that 90% of human settlements within the United Kingdom are net importers of CO_2 emissions (Minx *et al.*, 2013). This means that CO_2 emissions created to service the domestic demand are higher than the emissions created from the production within the national territory (OECD, 2017). This is a consistent trend as within most developed nations it can be more efficient to import goods produced in countries where the input factors are less expensive than those within the home country. Through their study, Minx et al (2013) shows that the carbon footprint of cities throughout the UK is mainly driven by socio-economic consumption patterns (Minx *et al.*, 2013).

In addition, both the lowest and highest carbon footprints can be found in urban areas and the carbon footprint is consistently higher in relation to CO_2 emissions in urban areas (Minx *et al.*, 2013). Numerous studies have found that urbanized regions produce more CO_2 emissions than both rural and semi-urban regions, which can mainly be attributed to consumption, population compactness and industrial manufacturing (Kennedy *et al.*, 2009; Heinonen and Junnila, 2011; Wang *et al.*, 2017). While it is understood that cities are a major driver of greenhouse gas emissions, it is possible to utilize the knowledge, creativity and resources that is created within these cities to help reduce these emissions (Kennedy *et al.*, 2009). Important to be noted is the significance of understanding the divergence between cities and rural areas in policy formation, as governments must address how they address the issues of climate change differently within the city as compared to the rural areas. Well throughout and executed environmental policies will in turn lead to healthier population, producing more economic output.

Within the United Kingdom a prior study has been conducted on the ability of smart cities to reduce CO_2 emissions. 15 cities were selected across the UK to test if smart city policy has led to a reduction in CO_2 emissions from 2005 to 2013 (Yigitcanlar and Kamruzzaman, 2018). The academic backing of this study is drawn from Alizadeh's (2017) analysis of smart cities around the world and questions smart agenda's and cities abilities to keep up with their promise of formulating green and inclusive urban environments (Alizadeh, 2017). Yigitcanlars (2018) study utilizes panel data on ICT, GDP, city green areas, population density, urban sprawl and polycentricity to test if by implementing a smart city has had an impact on reducing CO_2 emissions. The analysis is completed through the use of three regression models, pooled, fixed effects and random effects. While no strong evidence was found that smart cities do in fact help reduce CO_2 emissions, this study represents relevant empirical research on smart cities that can help lead to updated and more precise policies for smart cities.

As Christopher Kennedy (2009) has found, cities make an important contribution to greenhouse gas emissions (Kennedy *et al.*, 2009). Drawing from the concept of urban metabolism, the metabolism of a city can be referred to as the energy flows within the city. More broadly speaking, this can refer to the flows of water, materials and energy within the city (Kennedy *et al.*, 2009). In considering this, Kennedy seeks to explore how heating, transportation, waste etc. contribute to urban GHG emissions (Kennedy *et al.*, 2009). This study has shown that location, technology and economic factors play a significant role in GHG emissions. The location of a city in terms of global connectivity plays a crucial role in determining the consumption of fuel from shipping transportation via airplanes and ships (Kennedy *et al.*, 2009). Personal income plays a role in influencing GHG emissions as it impacts household consumption (Kennedy *et al.*, 2009). Finally, technology is concluded to have the ability to plat a major role in reducing the GHG emissions from cities (Kennedy *et al.*, 2009). With this in mind, it is interesting to see how in 2009 the world of academia had begun understanding the potential role that technology has in helping to lead to a more sustainable world.

A further study conducted by Yang, Li and Cao (2015) has shown that socioeconomic and spatial planning factors has had on CO_2 emissions in rapidly urbanizing cities throughout China (Yang, Li and Cao, 2015). Taking four Chinese megacities from the periods of 1990-2010, this study utilizing a unique cross sectional and time variant panel dataset to determine if socioeconomic, urban form and transportation factors has on CO_2 levels. Interesting enough the study has found that the technology level of a city and an increase in population density can have an impact on reducing CO_2 emissions (Yang, Li and Cao, 2015). As a result of this, we can see a trend in research leading to the question if the role that technology has played in both Kennedy (2009), Yang, Li, and Cao (2015) and Yigitcanlars (2018) studies have found a relationship between CO_2 emissions and technology then there is the possibility that smart cities play an important role in helping to increase global sustainability.

In 1992 the United Nations Framework Convention on Climate Change was an international treaty signed between 165-member states on the United Nations. The main objective of this treaty as aimed at stabilizing man made greenhouse gas emissions, which at the time had been identified as one of the leading causes of climate change (United Nations, 1992). The framework acknowledged the change in the earth's climate can be directly attributed to human activities resulting in the rapid increase of concentrations of greenhouse gases and in turn the warming of the earth. The treaty covers 26 articles in which general acknowledgment of climate change is confirmed and most of the onus is placed on developed countries to take the lead on this issue. In its essence the article promoted the change from entirely disregarding climate change to moving towards a far more aware world in which countries address this requires work but leaves this to be determined by the country itself. While the framework covers terms such as "acknowledging", "recognizing", "noting", "aware" and "affirming' no real mention of how to address these issues was outlined as the agreement was merely a non-binding guideline on greenhouse gas emissions and contained no enforcement mechanisms (United Nations, 1992). While the treaty in article 17 explicitly states the ability of all member states to enter into a protocol based on the convention, the rather tame and indefinite implications this treaty held, led to the creation of the Kyoto Protocol (United Nations, 1992).

In Kyoto, Japan 1997 a protocol was signed between the 37 of the industrialized countries of the United Nations Framework Convention on Climate Change states that commits all parties involved to reduce greenhouse gas emissions. This treaty was an extension of the United Nations Framework on Climate Change, in which its main objective was to stabilize greenhouse gas emissions throughout the member states. At this time a consensus had been reached that global warming was occurring and it was extremely likely that man-made CO_2 emissions were one of the major catalysts of this event. Recognizing that developed countries through major industrialization were contributing to greenhouse gas emissions and something needed to be done about it (UN, 1998). The majority of the responsibilities was placed on the more developed regions as they had traditionally responsible for the current levels of atmospheric greenhouse gas emissions. The act covers 6 greenhouse gases including carbon dioxide (C02), Methane (CH4), Nitrous Oxide (N20), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF6). The protocol in Article 3 concluded that carbon emissions do not exceed their assigned amounts calculated by the country specific emissions limitation and to reduce their overall emissions by at least 5 percent below the 1990 levels between the period of 2008-2012 (UN, 1998).

This set the stage for the gradual movement within the UK towards taking climate change more seriously. This recognition that climate change is a serious issue affecting ecosystems, and general human security has led to a sharp increase in adaptation and research regarding how households, cities, countries and sectors can respond to these evolving conditions (Aguiar *et al.*, 2018). The Climate Change Act of 2008 was the UK's first step towards minimizing its carbon footprint.

As of late, the United Kingdom has enacted a climate change act, to ensure a net balance of UK carbon emissions from all six of the Kyoto Protocol to be reduced by 80% to the 1990 baseline by the year 2050. The Climate Change Act of 2008 set the stage for the United Kingdom to move towards a low carbon economy by providing the ability for legislative measures aimed at greenhouse gas reduction targets to be enacted in government. These include carbon budgeting and proposals and policies for meeting the said carbon budgets (Parliament of the United Kingdom, 2008).

2.2 Climate Change

Climate change poses one of the greatest challenges of our time, by 2050, there will be approximately nine billion inhabitants that will require food, shelter and employment opportunities. Approximately two billion of these people will be migrating into the worlds cities from rural areas (WBG, 2016). These cities will have to employ, feed and provide shelter to residents all while reducing its carbon footprint and increasing its equity, quality of life and resilience. The World Bank, Organization for Economic Co-operation and Development (OECD) and the United Nations (UN) have all implemented climate change plans to help provide guidance and assistance to members and countries around the world in fighting climate change (United Nations, 2016; WBG, 2016; OECD, 2017) .

The OECD in their report *Green Growth Indicators* (2017) seeks to find an equitable way to increase economic development while remaining cognisant of climate change and sustainability (OECD, 2017). As countries begin to grow their economies a large list of negative externalities arises. Alongside this rising economic growth, is a strong environmental dimension in which countries should remain aware of. Large natural resource bases of freshwater, forests and oil can be a blessing for one's national economy but proper management of these is crucial. In today's world, large difference exists in economic growth and inequality (OECD, 2017). The OECD has focused on a method which is known as green growth, a multifaceted approach to growth in which all aspects of environmental degradation are considered while maintaining economic prosperity. These range from natural resources, consumption and production, air pollution, and the economic opportunities from innovation (OECD, 2017). Air pollution is arguably one of the greatest environmental health risks worldwide. Exposure to harmful pollutants from the production of materials and goods as well as, the consumption of raw materials have serious consequences for human health and the environment (OECD, 2017). Carbon dioxide (CO_2) is artificially created through the combustion of fossil fuels and its biomass accounts for approximated 90% of the total greenhouse gas (GHG) on earth (OECD, 2017). CO_2 emissions are the largest anthropogenic emissions on earth and are some of the easiest and most readily possible to mitigate. Greenhouse gas stabilization is a key factor in a countries ability to deal with climate change. Climate change is a global concern for its effects on human health, ecosystems, agriculture, extreme weather events and human settlements. If not dealt with properly, this in turn will affect both cities and people around the world. Reducing risks to human health from poor air quality is crucial to improving livability and quality of life within cities (OECD, 2017).

The World Bank Group (WBG), sees climate change as a threat to its core mission: to end world poverty and increase shared prosperity in a sustainable way (WBG, 2016). Released in 2016, the World Bank has a Climate Change Action Plan in place, aimed at continuous development. Research suggests that by 2050 the world will need to feed 9 billion people, provide affordable electricity for 1.1 billion people who currently live without it, provide clean, drinkable water for over 4 billion people facing severe water scarcity all while reducing emissions and transitioning away from fossil fuels (WBG, 2016). In the coming years, cities will welcome and approximate 2 billion new urban inhabitants, who will need livable housing, low carbon transport, ample employment base as well as access to suitable services. Based on this action plan, it is evident that the World Bank is committed to promoting the transition to a more sustainable form of economic development for its recipients and while a number of obstacles exist in achieving the goal of a sustainable earth the World Bank Group believes there is a large opening for interventions in this field, specifically in the use of big data in enabling cheaper and faster risk assessment of economic and environmental plans (WBG, 2016).

2.3 Smart Cities

The invention and evolution of technology is something that has changed the way the humans live, work and play. It has changed almost every facet of our lives and plays an enormous role in shaping the way we interact with each other, but it has also changed the way we interact with the city we live in. The concept of a 'smart city' is a relatively new phenomena that has taken over the world in the past 20 years. Everyone from academic researchers and city governments to the business and tech elite have started coming up with new ways in which information communication technology (ICT) and big data can be utilized to help the city progress and become more efficient. Although a large body of work has been compiled on smart cities, there still lacks an overall definition of what a smart city is. This section seeks to understand the origins and characteristics of a smart city.

Within academia, one of the more authoritative figures on smart city research is Giffinger *et al's* 2007 article, *Smart Cities – Ranking of European medium sized cities* (Giffinger, 2007). A combined effort from TU Delft, The University of Vienna and the University of Ljubljana, this paper is one of the most widely cited frameworks and definitions on smart cities. Here, Giffinger has concluded in his definition that smart cities are "well performing in a forward looking way through the economy, people, governance, mobility, environment and built on the smart combination of endowments and activities of self-decisive independent aware citizens" (Giffinger, 2007, p. 11). This definition from Giffinger *et al's* considers a crucial point of smart cities, as their forward-looking approach to urban development while approaching what are the key components of smart cities and linking them to neoclassical theories of urban competitiveness. Having this embedded in policy allows for a level of flexibility to adapt to the changing atmosphere within cities. By stipulating that a forward-looking approach is necessary, you avoid possible stagnation and becoming caught up on a single aspect of the project. This a crucial part of smart cities as not being caught up on one aspect will allow for adaptation in the changing city. In addition to this, a fundamental aspect of the framework is the mention of smart people as an aspect of a smart city (Giffinger, 2007). In the end a smart city is meant to improve the lives of those living there and well improving aspects of the city itself are very important, taking a strong link to both social and human capital is an important aspect (Giffinger, 2007). Concluding, this research paper presents a widely cited definition and framework for smart cities however, one final point is noted. While this analysis presents an overview of cities at a single point in time, the author identifies the limitations of this study as time series data was beyond the scope for this diverse of a sample size. That being said, the author speaks to how such an exercise would be extremely useful to determining the smart city progress rather than a moment in time (Giffinger, 2007).

Furthering the quest for a clear and concise definition of a smart city, Hollands in his paper *Will the Real Smart City, Please Stand Up* (Hollands, 2008) seeks to further the debate on the blurred definitions of the phenomenon. While it can be agreed upon that the integration of ICT into the built form is one of the major components of smart cities. Hollands determines that the four key elements of a smart city include the integration of ICT into the built form, an explicit point to include business led urban development, a concern for both social and environmental sustainability and most importantly here the inclusion of the human aspect into smart cities (Hollands, 2008). The emphasis of a human led approach is a crucial characteristic to this framework as this helps to set the divide between academic and business literature in smart cities research. Although it is clear that technology enables retrogression, Hollands stresses that this is not necessarily the most critical factor in defining a smart city (Hollands, 2008). Drawing from this, he continues to deduce that the integration of ICT into the built form should not only serve the global businesses working for their interests (Hollands, 2008). There needs to be an explicit mention on the integration of the social aspect of the citizens of this smart city. For a city to become smart in the end it needs to serve its citizens. A further point made is that by integrating a wide range of ICT and technological intensive uses into the city can marginalize those who are in a sense technological illiterate creating deeper social polarization (Hollands, 2008). Hollands takes a crucial step back from the self-congratulatory smokescreen of labelling a city as smart to identify two main problems arising from this. The first one being that by ushering in the technological smart city can act as a camouflage to a business dominated informational city where multinationals dominate the city and governments act desperately to retain the large companies. Second, the smart city label can create deeper social polarization by marginalizing those who are technology illiterate and unable to find work in a creative class. As such, Holland proposes that "the smart/creative city can become not only more economically polarized but also socially, culturally and spatially divided by the growing contrast between incoming knowledge and creative workers and the unskilled and IT illiterate sections of the local poorer populations" (Hollands, 2008).

Complimenting Hollands work, Caragliu *et al* in *Smart Cities in Europe* touch on the role of human and social capital as an important feature of smart cities. In this paper, a strong reliance on the prior definition of Giffinger is expanded on by utilizing the six axes as a framework building block (Caragliu, del Bo and Nijkamp, 2011). Caragliu *et al* find that when a city is smart its "investments in human and social capital and tradition transport and modern ICT communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (Caragliu, del Bo and Nijkamp, 2011, p. 70). Building off of the definition provided by Giffinger (2007), we can see that the evolution of the smart city remains in line with a strong proponent of this but takes a more environmental approach in this definition. This is in line with the trend of sustainability taking off within urban and regional planning around this time.

Batty *et al* in his article *Smart Cities of the Future* contributes to the goal of finding a clear and universal definition of a smart city. Here Batty stresses the role of ICT infrastructure and human and social capital as main features of the smart city (Batty *et al.*, 2012). While the definition of a smart city remains fuzzy, Batty seeks to further the academic discussion on the topic by providing insight into the topic from an economic perspective and continues the base of Giffingers six axes as the building blocks of his definition. Through a detailed overview of smart city literature, Batty aims to summarize the key characteristics of smart cities into six points that characterize the smart city, and act as the building block of his smart city definition. Batty *et al* believes that "a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources , through participatory governance" (Batty *et al.*, 2012).

Ronald Wall (2016) takes a unique approach to smart cities research by merging network analysis into the smart cities stream. To this point, world city network literature places an emphasis on a city's position within worldwide networks in which cities are connected through flows to measure success. Wall (2016) draws from network analysis theory to place cities in a world system in which the movement of goods and knowledge determines a cities place within the global hierarchy (Wall and Stavropoulos, 2016). By utilizing this methodology, he has found that global connectivity is an important factor in contributing to a cities level of smartness that other authors are ignoring. With this in mind this factor has been included in his study and besides location faction the local and global positioning of cities within the worlds FDI network is imperative to the smartness of cities (Wall and Stavropoulos, 2016). From this Wall (2016) has found that network characteristics play an ever-growing important role in a city's smartness.

Within the United Kingdom, a number of smart cities exists to date and many other are beginning to adapt their urban planning to make better use of this opportunity. The City of London in the Smart London Plan has identified 7 areas for improvement within the smart city framework and by 2020 wish to propel London to one of the smartest cities worldwide. In summary the plan includes increasing technical equity by ensuring all Londoners have the knowledge and know how, while mobilising the city to be a part of the change (Smart London Board, 2013). In addition to this the plan outlines their goals to increase open data, leverage the strong base of business, universities and populations, utilize technology to improve the monitoring of and quality of infrastructure, provide smart governance and utilize their place within the national and world network to ensure London is a better city for all inhabitants (Smart London Board, 2013). While the plan may be vague in nature, understanding that this what the future will hold and taking the first step is very important. An ambitious new environmental pan is currently under construction with one of its main targets to encourage new initiatives on major priority issues such as air quality improvements (Huawei and Navigant Consulting, 2016).

Within Scotland, the Scottish Cities Alliance has formed a strategic partnership between eight of Scotland's largest cities and regions. The partnership acts as a catalyst to development by promoting collaboration and inclusion between the cities. The programme is aimed at expanding smart city capabilities and deliver city priorities through improved community engagement and the integration of innovation and service delivery. The projects being implemented are from a diverse range of specialities including but not limited to: open data;

smart communities; smart services of energy, waste and public service; and smart infrastructure.

Partnerships between large technology companies and cities are becoming a new way in which smart cities can be built and designed. Not to be confused with a formal public private partnership, these plans help bridge the gap between technology and traditional city planning as tech companies can provide the ingenuity as well as the software and hardware and cities can provide the arena in which these can operate. An example of this comes from north of the border in Canada. Sidewalk Labs, an Alphabet subsidiary and Waterfront Toronto, a crown corporation in charge of the city's waterfront development have partnered together to implement a never been done before idea. The plan is to build the world's first master planned smart city in the downtown core of Toronto, Canada. While still within the development stages, this ambitious plan sets the stage for cities around the world to adopt a more forward-thinking technology driven approach to urban planning. The rough draft of the plan proposes a newly built neighbourhood on current brownfield sites located just east of the downtown core. These sites previously were home to a number of industrial yards that had been underutilised city land in the core.

Huawei has commissioned Navigant Consulting to run a UK Smart Cities annual report, with the aim of providing a deeper understanding of the current state of smart city development in the UK. This is achieved through the comparison of the top 20 leading smart cities within the Kingdom. The report identifies that we see the gap between smart city programmes and strategic priorities are beginning to be merged but still much work exists (Huawei and Navigant Consulting, 2016). An example of this being within the evaluation category for the index, which is divided into two dimensions, strategy and execution. In both cases the alignment of smart cities with the sustainability plans is explicitly mentioned (Huawei and Navigant Consulting, 2016). Within the strategy dimension, the city's sustainability strategy and the explicit targets set for energy consumption, greenhouse gas emissions and related goals is reviewed and within the execution dimension the environmental impact is evaluated to look at the achievements against these sustainability targets set within the environmental and sustainability programmes (Huawei and Navigant Consulting, 2016). Identified as leading the pack in sustainability is both Peterborough and Bristol, who have both consistently led in environmental programmes and circular economy innovations. In addition to this, in planning for the future of smart cities, air quality is one of the issues that is now being given a greater priority with many city programmes. Cities are now looking to improve congestion while utilizing better information services for mobility and adopt low carbo vehicles (Huawei and Navigant Consulting, 2016). From this report, it is evident that a number of cities within the UK are keen to begin the transition to a smart city and believe that sustainability and more specifically air quality are two crucial aspects that must be kept at the forefront of this development.

2.4 Hypothesis Development

A total of two hypotheses are tested for their validity. The first hypothesis concerns the key determinants as well as, spatial distribution of CO_2 emissions throughout local authorities within Scotland. Previous studies concerning CO_2 emissions within China have found a steady increase of Global Moran's I index for CO_2 emissions throughout the country from 1992 to 2013 (Zhou and Wang, 2018). The distribution of CO_2 emissions is relatively agglomerated with clusters of highly developed areas emitting higher levels of CO_2. It is reasonable to assume that through the history of economic development within Scotland's industrial revolution that the majority of CO_2 emissions are distributed in a similar fashion, being emitted from highly developed agglomerations with high clustering of CO_2 emissions. Linking with the first sub research question, the aim is to understand where emissions are located throughout Scotland.

Hypothesis 1: CO_2 emissions are spatially clustered along the agglomerations of cities throughout Scotland.

The second hypothesis is concerned with the labelling of city smartness. This research will solely use the definition of a smart city is one that is more connected, has higher levels of ICT, better transport and smart governance is in turn smarter. At the core of the transformations to become a smart city is these new technologies and data to help improve the city. This understanding that ICT is the leading factor of smart cities is embedded in the literature of Batty (2012). In addition, identified in the literature review is the understanding that larger cities with poor transport infrastructure in terms of multi-modal transportation and public transport are emitting the largest amount of CO_2 emissions (Kennedy *et al.*, 2009; Revi *et al.*, 2014; Yang, Li and Cao, 2015). Studies throughout China have shown that a decrease in private vehicle ownership implying an increase in public transit ridership will have a significant negative effect on CO_2 emissions at the 5% level (Yang, Li and Cao, 2015). Based on the literature it is reasonable to believe that a smart city would play a pivotal role in reducing the CO_2 emissions of cities over time as we have seen in studies conducted within China (Yang, Li and Cao, 2015; Zhou and Wang, 2018). A range of research has been conducted on the role of smart cities and ICT as a catalyst to reducing CO_2 emissions within the city (Kramers *et al.*, 2014; Aelenei *et al.*, 2016). This leads us to believe that by implementing a smart city agenda to push the project into fruition should have a significant impact on reducing CO_2 emissions in the United Kingdom and that transport, connectivity, and higher levels of infrastructure should be highly correlated with CO_2 emissions and serve as means for mitigating the negative externalities associated with it.

Hypothesis 2: Smart City Planning has contributed to reducing CO_2 emissions from 2005 – 2016.

2.5 Conceptual Framework

Smart city definitions are broad in nature, and over time have come to become an umbrella term for all sorts of innovations in the urban system (Anthopoulos, Janssen and Weerakkody, 2016). This paper has reviewed existing smart city literature consisting of prior conceptualization frameworks and performance measurement techniques divided into themes focusing on the role of infrastructure, the knowledge economy, human and social capital and smart governance to derive at a conceptual framework for environmental performance measurement. In addition to this, the literature review has identified that CO_2 emissions is one of the more harmful GHG's today and that cities play a large role in both contribution to these GHG's as well as in stabilizing and reducing them.

Giffinger (2007) looks at smart performance in a forward looking way and has concluded that there are six dimensions of an urban system, people, economy, government, mobility, living and environment and for a city to be considered smart it must ensure that these dimensions are smart (Giffinger, 2007). Utilizing this as a starting point for this analysis a number of different frameworks have been reviewed, combining the key factors of what it means to be considered a smart city. Angelidou (2015) sees smart cities as the intersection of technology and urban futures, the knowledge economy and innovation, and the technology push and demand pull of citizens and cities. This conceptualization takes into account all relevant stakeholders and depicts the integrated model of smart cities in four assets moving towards four assets (Angelidou, 2015). This perspective takes a strong approach towards human and social capital as key assets to promote growth within the city. Without a largely informed, empowered citizen base a smart city will not achieve advancement of human and social capital, which is one of the main goals of smart cities. There is a direct link between these two frameworks, connecting the citizen centred approach and without a knowledge economy promoting innovation this cannot be achieved.

Figure 3: Conceptual model of smart cities environmental performance

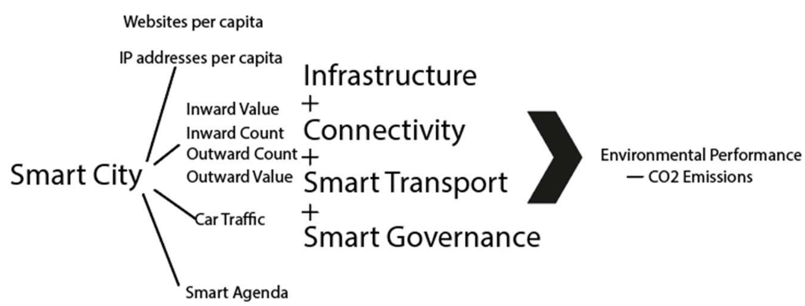


Figure 3, the model of smart cities environmental model represents the conceptualization of how a smart city's environmental performance impacts CO_2 emissions. Based on the literature surrounding smart cities, the underlying aspects of smart cities were conceptualized. This is represented by the busy visualization of a smart city with a large number of inputs surrounding it. While smart cities are complex systems with a diverse range of inputs, four pillars exist throughout all. These are smart infrastructure, connectivity, smart transport and smart governance. The four pillars are a combination of a number of different concepts surrounding smart cities. These range from Giffinger (2007), Angelidou (2015) and Wall (2016). As well as, cities frameworks from around the world including the City of London Smart Plan, Scottish Cities Alliance and The City of Toronto and Googles Smart City. On the right side of the model, shows the connection between cities and the environment. A number of governmental bodies have referred to cities as extremely important aspects of increasing sustainability as they play one of the largest roles in mitigating climate change. The World Bank (2016), and the IPCC (2014) have both referred to cities as one of the leading facets of the modern world that can help to mitigate climate change.

Chapter 3: Data, methods and measures

The main objective of this research is to determine whether the presence of smart city planning has had an impact on the sustainability of the city, in terms of CO_2 emissions. This will be conducted in a three-step process. The first step will be to determine what constitutes a smart city and the operationalization is conducted to outline the specifics behind this phenomenon. Second, an understanding of climate change within the UK will be observed through geographic information software and a spatial analysis of emissions. Finally, both panel and spatial panel regression models will be conducted to determine the impacts of the levels of city smartness between 2005 and 2016 on the emissions of cities throughout Scotland.

3.1 Data

3.1.1 CO_2 emissions data

Based on the literature review, research objectives and the nature of available data, the dependent variable is defined as UK local authority and regional estimated CO_2 emissions per capita from 2005 to 2016, drawn from the National Statistics Bureau. According to the OECD, air pollution and harmful emissions are the single greatest environmental health risk that our world is facing and thus, reducing the exposure to risks associated with negative health effects from degraded air quality is central to cities, governments and policy (OECD, 2017). Within the United Kingdom carbon dioxide levels have increased 45% since the industrial revolution (Department for Busienss Energy and Industry Strategy, 2014). The stark increase in CO_2 is almost entirely due to human activity, caused by various other sources the burning of fossil fuels, agricultural and deforestation and the manufacturing of cement, chemicals and metals (Department for Busienss Energy and Industry Strategy, 2014). Reducing these harmful emissions, both national and globally will have an important impact on not only reducing the earth's temperature levels but will help to reduce the harmful negative externalities associated with climate change such as the health risks from air pollution.

The CO_2 emission statistics are drawn from a combined database from the UK's Greenhouse Gas Inventory as well as, data included from a range of other sources, such as local energy consumption statistics. The data shows emissions allocated on an end-user basis where the emissions are distributed based on the point that the energy is consumed rather than created. The one exception to this being the energy industry where emissions are tracked from the production of goods and are assigned to where the production takes place. CO_2 emissions are the main GHG and account for approximately 81 percent of the UK's greenhouse gas emissions in 2016. This data has helped to drive the increasing emphasis on the role of regional bodies and local governments and their contributions to energy efficiency improvements.

3.1.2 City smartness data

Throughout academic, government and business literature on smart cities, ICT infrastructure is highlighted as a backbone of any city that wishes to become 'smart' (Arup, 2010; Batty *et al.*, 2012; Department for Business Innovation & Skills, 2013; Yigitcanlar and Kamruzzaman, 2018). As a result, this study uses three main indicators of smart city planning and city smartness to representing the integration of ICT infrastructure into the fabric of cities. These are the number of websites per capita for each city, number of IP addresses per capita for each city and the presence of a smart agenda. The data for these variables is collected from a range of different sources including both governmental and independent sources. This data was collected from government reporting and open data as well as, MYIP.com. The presence of a smart agenda was conducted through the examination of each cities policies towards smart cities and data. Policies analyzed were those surrounding open data, smart services (energy, mobility, waste, public safety, innovation labs and smart water management). The presence of smart city planning is treated as a binary variable to indicate a yes or no indication of if smart city policy exists.

3.1.3 Connectivity

Based on the work conducted by Wall (2016), city connectivity is understood as the level of foreign direct investment through the city. By understanding a city's place in the world's systems network we are then able to understand the level of city smartness. While most smart city and evolutionary economics authors are ignoring this indicator as a factor of city smartness, by utilizing it we can understand the level of smartness through an interesting new lens (Wall and Stavropoulos, 2016). The top cities throughout the world are the most connected, they are the cities at the forefront of innovation. This innovation can occur over a wide range of services, but it is the connectivity in terms of a world cities network that is important. The largest global cities in the world are the most connected. For this study the level of city connectivity is measured through inward and outward flows of FDI in terms of both count and value of trade. This data was sourced and aggregated from FDImarkets.com.

3.1.4 Socioeconomic data

The control variables are utilized to reflect the different city context. These are collected from the national statistics bureau and include context of market size, and the economic efficiency of the city. As prior studies have found linear relationships between CO_2 emissions and economic efficiency of a region (Yang, Li and Cao, 2015). This study will exclusively use the gross value added per capita to represent socioeconomic indicator.

3.1.5 Sample Size

The selection for the location of this study was reliant on two constraints, the availability and consistency of data and the number of classified smart cities within the region. To approach the first constraint, it is necessary to specify the research on a single region that offered a diverse range of standardized statistics to ensure consistency throughout the database. The availability of data was an issue that led to narrow proposal to developed regions, with a wide range of data collected over a respectable time frame. Europe, North America and Asia were all possible candidates for this proposal. From this an analysis on Canada, The United States, The European Union, Denmark, Sweden, Norway, The Netherlands, Germany, China, Japan and South Korea were all conducted. The main issue encountered in this step was related to the city level data required for this research, in which a large majority of these options did not provide. While all countries included in the analyse have a large amount of national and regional statistics available, The United Kingdom, Sweden and China had the largest and most diverse data sets of city specific data. All of which had to be collected by a single organization in order to avoid discrepancies within the data. The United Kingdom was the strongest candidate as, it has a long history of strong governance and data collection, clearly designed and designated countries, provinces and local authority levels. The UK has been one of the earliest adopters of smart cities throughout the kingdom which according to Caragliu, del Bo and Nijkamp (2011) is one of the key determinates of smart city's (Caragliu, del Bo and Nijkamp, 2011). While Sweden, the UK and China are all early adopters and have a wide large number of smart cities, Scotland proved to be the best possible option for this analysis as the quality and level comes from a unified body, while the country has a relatively large division in urbanization exists. Considering these characteristics, it is possible to determine the differences in smart city planning compared to those of non-smart cities while having a wide range of consistent data across the region. To determine the appropriate sample size for this study the aforementioned data as aggregated and combined LAD shapefiles to provide a geospatial understanding of the data.

3.1.6 Indicators

Table 1: Smart city indicators

Grouping	Classification	Description	Comprehension	Source
Sustainability	The estimated level of CO_2 emissions per capita per year	The per capita estimation of CO_2 emissions from industry, domestic, transport and LULUCF	The lower the level of CO_2 emissions per capita per year indicates a more sustainable city	UK National Statistics Bureau
Infrastructure	The information communication technology integrated into the built form	Quartile classification of the number of websites Quartile classification of the number of IP addresses hosted	The higher number of websites hosted means a higher level of smartness The higher number of IP addresses hosted means a higher level of smartness	MYIP.com
Smart Transport	The use of technology to improve the transport and efficiency of travel within a region	The vehicle traffic in kilometres by local authority	The lower the level of car traffic per capita per year indicates a smarter city	UK Department for Transport
Connectivity	Local and global connectivity	The indegree of the city based on the FDI value showing the prestige or attractiveness to others - The outdegree of the city based on FDI values showing power or influence over other cities	The higher level of indegree the smarter the city The higher the level of outdegree the smarter the city	FDIMarkets.com

Smart Governance	Smart governance comprises the facilitation as well as the empowerment of citizens to progress and innovate	The presence of a smart agenda within the urban planning framework	The presence of a smart agenda implies the government's commitment to innovation and progress	Binary variable drawn from multiple governmental sources
Socioeconomic Classification	GVA/Capita	The level of GVA/Capita/Year	The higher the GVA/Capita/Year, the higher the level of socioeconomic development	UK National Statistics Bureau

Table 1 shows the indicators that are utilized in the conceptualization of smart cities and environmental performance. The grouping, classification, description and comprehension columns, represents the grouping pillar that is utilized in the conceptualization as linked to the conceptual framework, the definition and description of the indicators as well as, how the indicator should be comprehended for this study. The final column shows the source where the data was collected from.

3.2 Research Methods

The research strategy is conducted through a number of inferential analyses including spatial autocorrelation analysis as well as both panel and spatial panel regressions to assess the relations between CO_2 emissions and smart cities. The city smartness indicator is divided into quartiles to better assess the differences in effects of city smartness on CO_2 emissions. The data is divided into equal quartile portions with cities with a highest number of websites per capita being in the 4th quartile and those with the lowest number of websites per capita being in the 1st quartile. The same transformation was done to the IP addresses. This method is based on a similar study conducted by Kamruzzman and Yigitcanlar (2018). In doing so this helps to distinguish which cities are considered smart and which are considered to non-smart traditional cities. In addition to this, the presence of a smart agenda is utilized to understand the level of smart city planning within the city.

To answer the first sub question, a review of the leading smart city researchers will be compiled into a clear chart showing the differences in understanding of what a smart city is from academia to business. This will provide further insight into the broad understanding and vagueness of the phenomena known as smart cities. While the four pillar characteristics of Infrastructure, Smart Transport, Connectivity and Smart Governance are being used to encompass the working definition of a smart city, it is beneficial to understand other ideologies within the field.

To answer the second sub-question a spatial analysis will be conducted on Scotland to determine if there is clustering of CO_2 emissions other than that of random chance. A fundamental concern of spatial analysis is to identify patterns within the data and identify if this pattern signifies that something is out of the ordinary or something out of the ordinary has occurred within one or more regions within the dataset (Getis and Ord, 1992, 2001). The industries that will be reviewed include, Industry and Commercial which includes a subset of Industry and Commercial Electricity, Industry and Commercial Gas, Large Industrial Installations, Industrial and Commercial Fuels, Agriculture, Domestic which includes a subset of Domestic Electricity, Domestic Gas, Domestic Other Fuels, Transport which includes a subset of Total Road Transport on A roads, Road Transport on motorways, Road Transport on minor roads, Diesel Railways, Transport Other and Land Use, Land Use Change and Forestry

(LULUCF) Net Emissions. The spatial analysis techniques that will be utilized include the Global Moran's I and the Getis-Ord Gi Statistic. The Global Moran's I statistic is a measure of spatial autocorrelation to determine whether the pattern expressed is clustered, dispersed or random and the Getis-Ord Gi statistic to see the hot/cold clustering of CO_2 emissions throughout the sample. This will answer the hypothesis that CO_2 emissions are clustered within the largest cities in the United Kingdom as a result of large industrial manufacturing.

Finally, a statistical investigation will be conducted to observe the sustainability performance measurement of smart cities within Scotland from 2005 to 2016. The data consists of cross-sectional time series data to measure the difference between cities as well as the difference within cities over time. The independent variables range from ratio, interval, time varying and time invariant data. A magnitude of challenges exists regarding the complexity of these variables. The indegree and outdegree of the cities will be calculated utilizing the FDI data drawn from FDI markets (Opsahl, Agneessens and Skvoretz, 2010). Panel date will be utilized as it will account for individual heterogeneity across individual cities (Hill, Griffiths and Lim, 2008). To determine the appropriate model to run based on the unobserved effects both a fixed and random effects models and the Hausman test.

3.3 Data Analysis Measures

The sustainability of cities, which is measured through estimate CO_2 emissions per capita of the selected cities. The database consists of both cross-sectional and time variant data which allows us to study a number of distinctions and changes between the cities. In addition, this allows to observe the changes within and differences of cities as well as the changes of cities over time. The dependent variable is a continuous in nature and changes in both time and across cities. The independent variables consist of binary, interval and ratio data. To begin a spatial analysis will be run to determine the clustering of emissions throughout the UK as well as, to determine the Global Moran's I index scores of each subset of CO2 emissions. A further statistical analysis will be conducted on the panel data to observe and determine the correlations and impacts that the selected variables have on CO_2 emissions over time as well as the effects that smart city policies have on the sustainability of cities. Considering the complexity and nature of the of the dependent, independent and control variables and the challenge to find an appropriate model for the data, three models will be run as outlined below. Fixed-effects, and random-effects models will be used in conjunction to determine if the selected variables are correlated with CO_2 emissions and if implementing a smart city policy has an impact of CO_2 emissions of cities across Scotland. Adding to the reliability of the research, the Hausman test will be run to find the preferences between the fixed and random-effects.

Understanding the geographic distribution of sources of carbon dioxide emissions can aid policy in combatting climate change. The geographic distribution of emissions does not affect the climate impact of greenhouse gas emissions, but the distribution of economic activity and energy consumption does affect local regions which are the source of emissions. Combatting global climate change will require multilateral, international agreements but the fight against local climate change will start at home (Zhao, Burnett and Fletcher, 2014).

The spatial analysis conducted in this research concerns the spatial interaction effects among geographical units, in this case the cities. The goal of this approach is to understand the dependence among observations across time and space. When studying patterns in a spatial context, it is typical to assume that those observations that are closer together have a higher likelihood of being similar (Getis and Ord, 1992; Elhorst, 2014). This research will deal with two panel data models commonly used in research (fixed effects and random effects) and extend these traditional models to include spatial error autocorrelation and a spatially lagged dependent variable. As a result, this study will utilize 6 models.

A common method of estimation is the maximum likelihood (ML). The methods employed in this study are the ML implementation for both random and fixed effects models. (Kapoor, Kelejian and Prucha, 2007). The model differs from the traditional panel models and will be compared against the panel models by introducing a spatial autoregressive term in the dependent variable and spatially autocorrelated error term. (Millo, 2012). To denote the spatial component of the analysis, a spatial weighted matrix W will be used, which describes the spatial arrangement of the geographical units within the sample (Elhorst, 2014). The main purpose of these spatial econometric models employed is to test for the spatial interaction effects and the spatial spillover effects (Elhorst, 2017).

3.3.1 Global Moran's I Statistic

In spatial analysis, the spatial autocorrelation or Global Moran's I is a tool that measures spatial autocorrelation based on feature values, in most cases being point data and locations. The study evaluates whether the pattern expressed is clustered, dispersed or random and the output is in the form of the Moran's I Index value together with both p-values and z-scores. Global Moran's I calculation is an inferential value and is understood within the context of the corresponding

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}, \quad (1)$$

null hypothesis. The null hypothesis for the Global Moran's I statistic always states that the attributes analyzed in the study are randomly distributed among the features within the study. For this study, the null hypothesis is that the distribution of CO_2 emissions is randomly distributed throughout Scotland.

The spatial autocorrelation statistic is applied to determine whether there is spatial autocorrelation or clustering of the residuals. The spatial independency of the residuals was assessed with the global spatial autocorrelation coefficient. Moran's I measures the spatial autocorrelation based on city locations and their simultaneous values. Otherwise understood as zero cross regional correlation amongst CO_2 emissions in Scotland. The results will show whether the cities are clustered, dispersed or random. Global Moran's I Statistic. Moran's I is specified as:

$$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}. \quad (2)$$

where w_{ij} is the weight between the observation *i* and *j,* which is determined by whether *i* and *j* are adjacent neighbourhoods. S_0 is the sum of all w_{ij}'s.

3.3.2 Getis-Ord Gi Statistic

The Getis-Ord Gi Statistic measures clusters of features within a dataset to determine high or low clustering patterns. The algorithm will produce an output of statistically significant hot and cold spots represented geographically. The outputs are in the form of GI bins, z-scores and pvales and are corrected for multiple testing and spatial dependence using the false discovery rate correction method (Getis and Ord, 1992). The resulting map will display features ranging from +/- 3 bins, with bins at either +3 or -3 are statistically significant at the 1% percent significance level; bins in the +/- 2 are statistically significant in the 5% percent significance level; bins in the +/- 1 are statistically significant at the 10% percent significance level and those with 0 are not statistically significant.

The z-score is a measure of standard deviation of the sample size and will provide a high/low clustering indictor. Within spatial analysis and network analysis the null hypothesis is the assumption that the pattern is one of hypothetical random chance. The z-score is a tool that in this case is used to test the statistical significance to help decide whether or not to reject the null hypothesis. The null hypothesis of this study is that CO_2 emissions are not clustered in any significant pattern. The larger the z-score, the more intense the clustering of high values, resulting in a hot spot. Conversely, the same outcome exists for smaller z-score. The smaller the -score the more intense the clustering of low values or cold spots. The study is expected to have high values clustering in hot spots around more industrialized regions.

3.3.3 Spatial Weights Matrix

The spatial weights matrix specifies the spatial relationship in the econometric model. In spatial analysis it is common to expect that close observations are more likely to be similar than those that are far apart. In its simplest form, this can be quantified by giving weights to pairs associated with neighbours as 1, 0 otherwise and $W_{ij} = 0$ as a city cannot be adjacent to itself. The matrix is a N x N matrix that defines the spatial arrangement of the spatial units (Elhorst, 2014). The elements of the matrix contain the spatial relationship between the observations *i* and *t.* This can be in the form of either the specification of distance between the two observations or whether the observations are neighbours. For this study, the specification of whether or not observations are neighbours will be used. Neighbouring cities have a higher likelihood of spillover from a region with more CO_2 emissions. The matrix has been normalized so that the elements of each column sum to one. The binary continuity matrix is constructed so that each neighbouring observation is defined by $W_{ij} = 1$ with all remaining observations as zero, as they are not assumed to be neighbours and so are the elements on the diagonal because on observation cannot be a neighbour of itself (Elhorst, 2014, 2017).

$$W_0 = \begin{pmatrix} 0 & w_{1,2} & \cdots & w_{1,N} \\ w_{2,1} & 0 & \cdots & w_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ w_{N,1} & w_{N,2} & \cdots & 0 \end{pmatrix}, \text{ were} \qquad (3)$$

$$w_{ij} = \begin{cases} 1 & \text{if } i \text{ is a neighbour of } j \\ 0 & \text{otherwise} \end{cases}$$

3.3.4 Fixed Effects Regression

The fixed-effects regression is a statistical model in which the model parameters are fixed to include only the non-random measures. This model will control for all time-invariant differences between cities, as such the estimated coefficients of this regression cannot be biased because of time-invariant characteristics of the city, an example of which being city culture city vision (Yigitcanlar and Kamruzzaman, 2018). The fixed-effects model will remove the effect the time invariant variables may have so it is possible to assess the effect of the predictors classified as ε_{it} on the dependent variable. Finally the fixed-effects model assumes that every city is different and the error terms and constant should not be correlated with other cities (Yigitcanlar and Kamruzzaman, 2018). The basic fixed effects model is specified as:

$$y_{it} = \alpha_i + X_{it}\beta + \varepsilon_{it} \quad (4)$$

Where $i = 1,\ldots.N;\ t = 1,\ldots\ T;\ Y_{it}$ is the dependent variable; X_{it} is a vector of the explanatory or independent variables; a_i are the time invariant individual components and ε_{it} is the error term. β is the coefficient to be estimated.

City networks both geographically and economically are interconnected, and neighbouring units are likely to have similar attributes. Thus, the different spatial units are expected to influence each other both directly and through unobserved factors. The traditional fixed effects model can be extended to include a spatial component, including the spatial autocorrelation component into the regression.

3.3.5 Random Effects Regression

While the fixed-effects regression controls for all time-invariant differences between the cities the random-effects model does not. The rationale behind the random effects model is that, unlike the fixed effects model, the variation across cities is assumed to be random and uncorrelated with the independent variables. With this, it is reasonable to assume that if there is substantial evidence to support that the random differences across cities then it is feasible to use the random effects model. For this, the same model is used as the fixed effects model.

$$y_{it} = X_{it}\beta + \varepsilon_{it} \quad (5)$$

where:

$$\varepsilon_{it} = \mu_i + v_{it} \quad (6)$$

Where $i = 1,\ldots..,N;\ t= 1,\ldots.,T;\ \mu_i$ is the cross-sectional random component; v_{it} is the idiosyncratic error term and both are independent.

3.3.6 Spatial Panel Models

Spatial econometrics is an over encompassing term that describes the intersection of spatial analysis and econometrics. Specifically, this approach is when econometrics models include parameters such as spatial autocorrelation or other neighbourhood effects, traditionally only found in spatial analysis. Spatial variables are integrated into the models by incorporating a spatial lag operator. In theory the spatial lag operator can be applied in a combination of any of the following the dependent, independent and error terms.

The spatial lag model theorises that the dependent variable depends on the dependent variable observed in neighbouring units as well as on a collection of observed local characteristics. This can be understood in regard to this study as that the amount of CO_2 depends on both the amount within other cities, spilling over and the local characteristics influencing this. The spatial lag model is considered as the formal specification for the equilibrium outcome of a spatial interaction between the cities within the study. In theory the interaction that occurs in this case is the relationship between the cities in regard to emissions and smart city planning and those occurring in nearby jurisdictions. The spatial lag model can be specified as:

$$y_{it} = \delta \sum_{j=1}^{N} w_{ij} y_{jt} + \boldsymbol{x}_{it} \boldsymbol{\beta} + \mu_i + \varepsilon_{it}, \tag{7}$$

Where δ is called the spatial autoregressive coefficient and W_{ij} is the spatial weights matrix designating the spatial arrangements of the units within the study.

The spatial error model proposes that the dependent variable depends on a group of observed local characteristics and that the error terms are correlated across jurisdictions. In regard to this study, this includes all unobserved factors that might influence the emissions and smart city planning that have been omitted from the model. The spatial model can be specified as:

$$\begin{aligned} y_{it} &= \boldsymbol{x}_{it} \boldsymbol{\beta} + \mu_i + \phi_{it}, \\ \phi_{it} &= \rho \sum_{j=1}^{N} w_{ij} \phi_{it} + \varepsilon_{it}, \end{aligned} \tag{8}$$

Where ϕ_{it} specifies the spatially autocorrelated error term and ρ is the spatially autocorrelation coefficient.

The spatial models differ from the non-spatial panel models in 9

3.3.6 Spatial Hausman test

The Hausman test checks for any correlation between the error components μ_I, which is the cross-sectional random error component and the regressors in a random effects model. Hausman test compares both random and fixed effects estimators and examines whether or not the random effects assumptions can be supported by the provided data. The Hausman test takes the form of:

$$H = NT(\hat{\theta}_{FGLS} - \hat{\theta}_W)^\top (\hat{\Sigma}_W - \hat{\Sigma}_{FGLS})^{-1} (\hat{\theta}_{FGLS} - \hat{\theta}_W) \tag{9}$$

where θ_{FGLS} and θ_W are the spatial GLS and within estimators and $\sum_W$ and $\sum_{FLGS}$ are the corresponding estimates of the coefficients variance (Millo, 2012).

3.4 Robustness Analysis

Through the use of spatial econometrics, this research process aims to find the intersection of data science and spatial analysis. Panel data models examine group effects, time effects of both in order to deal with heterogeneity or the individual effect that may or may not be observed. The fixed effects model explores if intercepts vary across groups or time periods. The random effects model examines differences in error variance components across the groups and time periods.

Outlier detection. The presence of outliers in the dataset can lead to misestimation and biased results. Outliers were detected and dealt with accordingly though observations within the linear scatterplots of each variable.

The use of panel data offers a number of benefits to this study. It controls the variation of time series and cross sections simultaneously. Cities change over time and while co-variation might exist between cities, they remain heterogenous. With that being said, the use of panel data can control for individual heterogeneity, which gives more informative data and less collinearity amongst the variables. Regression analysis that does not compensate for spatial dependency can have unstable parameter estimates and yield unreliable significance tests. Spatial regression models capture these relationships and do not suffer from these weaknesses. It is important to be mindful as these spatial dependencies are not to be seen as a source of information other than a correlation.

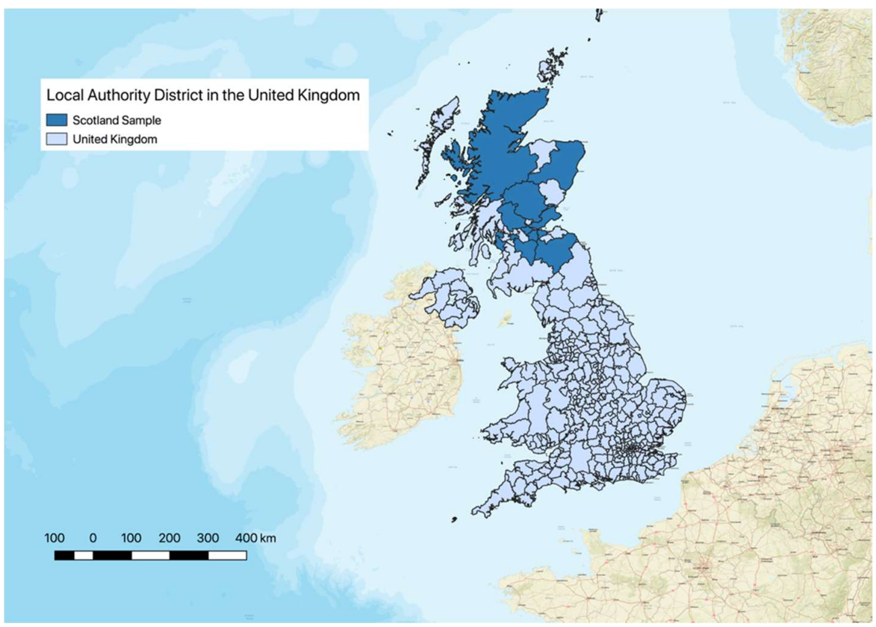
Chapter 4: Research Findings

This chapter will provide insight into the research findings of this study. The goal of this section is to explain the spatial distribution of CO_2 emissions and the relationship between smart cities and CO_2 emissions. The research questions and hypothesis will be explored in more depth throughout this section.

4.1 Overview of the Research Area

The geographical region for this study is conducted across fourteen LAD's within Scotland. These are ranging in both geographic and population sizes. The term local authority district is a general term used to cover a number of different authorities across the United Kingdom and includes London Boroughs, Metropolitan Districts, Unitary Authorities and Non-Metropolitan Districts throughout England, Unitary Authorities in Wales, Council Areas in Scotland, and District Council Areas in Northern Ireland. In total there are four hundred and eighteen different local authority districts in the United Kingdom. The figure below, represents every single local authority district within the United Kingdom, with those shaded in dark blue representing the LAD's included in this study.

Figure 4: Location of study



As shown in Figure 4, the darker shaded areas encompass the LADs included within the study and the lighter shaded areas are those LADs excluded from the study. As of December 2017, are 371 local authoritative districts in England, 32 of which are considered London Boroughs. This study has been conducted on 14 LADs in Scotland.

4.2 Descriptive Statistics

Table 2: Descriptive statistics of variables

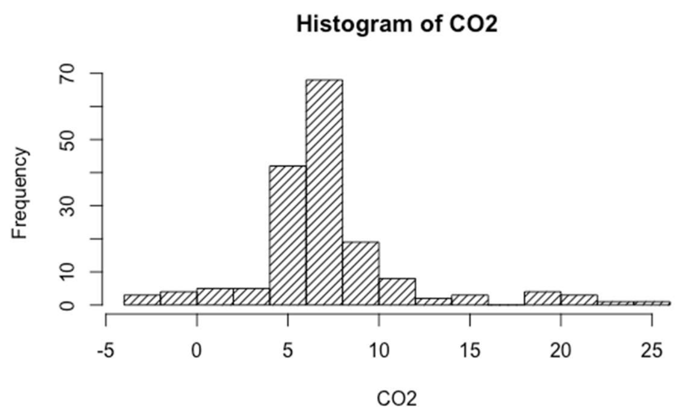
Descriptive Statistics

Variable	Variable Description		Mean	Std. Dev.	Min	Max	Observations
City ID	The ID of the City	overall	7.5	4.04	1	14	N = 168
		between	-	4.18	1	14	n = 14
		within	-	0	7.5	7.5	T = 12
Year	Observation Year	overall	2010.5	3.45	2005	2016	N = 168
		between	0	0.00	2010.50	2010.50	n = 14
		within	-	3.45	2005	2016	T = 12
CO2 Per Capita	Per capita CO2 emissions (tons)	overall	7.12	4.26	-3.51	24.30	N = 168
		between	-	4.14	-0.59	18.88	n = 14
		within	-	1.45	3.46	12.54	T = 12
Websites	Quartile classification of the number of websites hosted	overall	1.93	1.17	1	4	N = 168
		between	-	1.2	1	4	n = 14
		within	-	0	1.93	1.93	T = 12
IP Address	Quratile classification of the number of IP addresses	overall	1.93	1.23	1	4	N = 168
		between	-	1.27	1	4	n = 14
		within	-	0	1.93	1.93	T = 12
Car Traffic	Car traffic (KM) per local authrity district	overall	1437.94	5236.52	416	2874	N = 168
		between	-	5360.34	432.08	2753.92	n = 14
		within	-	761.90	1349.60	1558.02	T = 12
GVA per Capita	Per capita GVA relatates to the value added by production activity in a region	overall	5715.46	5236.52	1203	20371	N = 168
		between	-	5360.34	1330.08	17534.08	n = 14
		within	-	761.89	2983.05	8787.05	T = 12
Inward Value	The total value per year of FDI coming into local authority district	overall	104.93	231.22	0	1373.63	N = 168
		between	-	181.83	0.13	522.23	n = 14
		within	-	150.26	-267.72	956.33	T = 12
Inward Count	The total count per year of FDI coming into local authority district	overall	5.607	9.09	0	38	N = 168
		between	-	8.48	0.083	23.5	n = 14
		within	-	3.93	-9.05	21.94	T = 12
Outward Value	The total value per year of FDI out of each local authority district	overall	79.51	215.68	0	1798.99	N = 168
		between	-	148.56	0.75	489.09	n = 14
		within	-	160.93	-326.28	1389.41	T = 12
Outward Count	The total count per year of FDI out of each local authority district	overall	4.19	8.55	0	41	N = 168
		between	-	7.75	0.083	22	n = 14
		within	-	4.13	-12.8	23.19	T = 12
Smart Agenda	The presence of a smart agenda	overall	0.09	0.29	0	1	N = 168
		between	-	0.11	0	0.33	n = 14
		within	-	0.28	-0.24	0.93	T = 12

Table 2 shows the descriptive statistics of the data used in this study. Given the nature of the data as panel, the table presents three variations in data (overall, between the 14 cities and within a city for the 12 years. The overall, between and within are used for to describe the cross-sectional nature of the data. Overall statistics are ordinary statistics, based on the 168 observations within the dataset. Between statistics are the summary statistics for the 14 cities regardless of the time period and the within statistic is the summary statistic for the 12 time periods regardless of the city. The next variable is the time dimension of the data and ranges from 2005 to 2016. These two variables are used in conjuncture to classify the panel nature of the data. The CO_2 emissions per capita is the main dependent variable used in the research. The mean value of the emissions is 7.12, meaning that 7.12 tons of CO_2 are emitted per person per year. The standard deviation of this variable is -0.71 tons with the overall and between variations at 0.77 and 0.01. This means that there is a greater variation of CO_2 emissions within cities than between the 14 cities or overall.

Figure 5 shows the histogram of CO_2 emissions; the distribution of this histogram is strongly skewed to the right as the right tails are much longer than the left tails for this data. This exhibits that there is a large majority of the data with 0 – approximately 30 tons per capita and a number of outliers. The most obvious answer to this is the city of London which after a further investigation is the largest outlier with a minimum value of 117.55 and a maximum value of 245.08 in 2013. The blue line represents the kernel density of the data showing again a strong skewedness to the right.

Figure 5: Histogram of CO_2 emissions



The research uses three key independent variables as exposure variables, these are the number of websites hosted within a LAD and number of IP addresses within a LAD and the presence of a smart agenda in the LAD. The websites and IP addresses data has been transformed into equal break quartiles. This will result in a range between 1 on the lower 25% of websites and IP addressed per city and 4 being the highest 25% of websites and IP addresses per city. An important feature of these variables is that the within standard deviation is zero for both, meaning that these variables are time invariant and do not change within the city over time. The smart agenda is a binary variable representing if a smart agenda or policy aimed at smart cities exists within the city from 2005-2016. This is shown on a range of 0 to 1 as the dummy variable.

4.2.1 City Smartness and CO_2 emissions descriptive findings

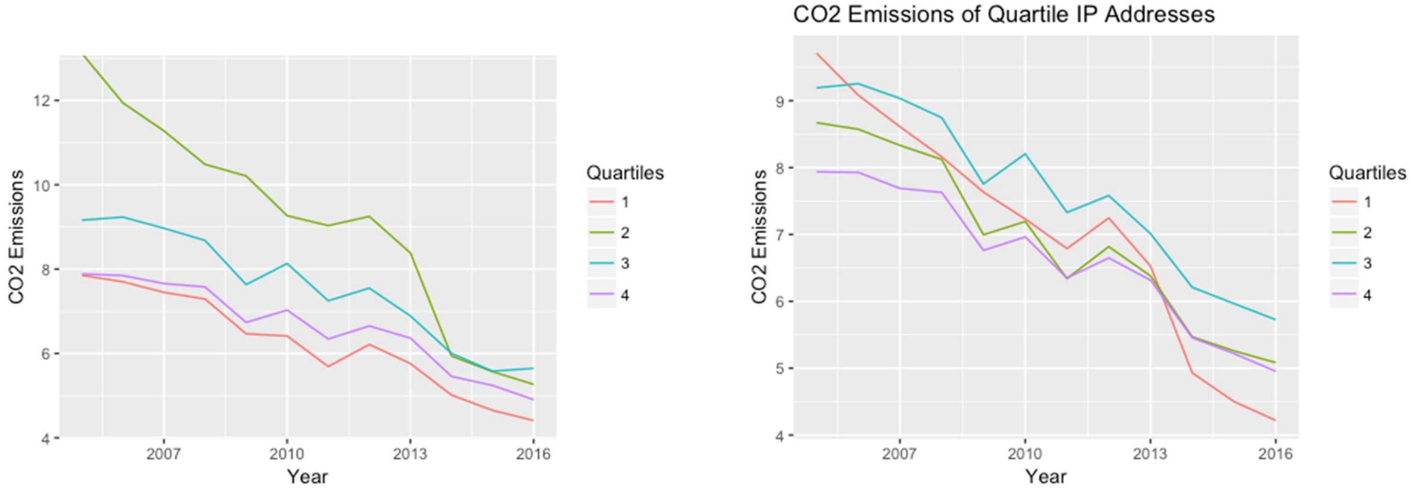
Table 3 shows the correlation matrix with the correlation coefficients for the dataset. The correlation coefficients are interpreted as an index of the linear relationship between the variables within the dataset. Interpretation of the correlation coefficient is on a -1 to +1 scale, in which -1 represents a perfectly negative linear relationship and +1 represents a perfectly positive linear relationship. Hypothesis two states that it is assumed there will be a reduction in CO_2 emissions over the study's time period. As such, the study has hypothesized that in theory as smart cities are partially intended to help increase the sustainability of the city, then there should be a strong negative linear relationship between the dataset and CO_2 emissions.

The correlation matrix shows a weak negative linear relationship between all variables except for the Inward Count of FDI transactions into a city. While all variables except for Inward Count exhibit a negative correlation matrix, none are significant.

Table 3: Correlation matrix

	CO2	Websites	IP Addresses	Car Traffic	GVA Head	Inward Value	Inward Count	Outward Value	Outward Count
CO2									
Websites	-0.037								
IP Addresses	-0.044	0.851							
Car Traffic	-0.101	0.462	0.449						
GVA Head	-0.104	0.797	0.827	0.747					
Inward Value	-0.064	0.614	0.669	0.408	0.721				
Inward Count	0.150	0.650	0.716	0.473	0.827	0.745			
Outward Value	-0.007	0.486	0.550	0.292	0.552	0.494	0.476		
Outward Count	-0.052	0.652	0.772	0.325	0.744	0.654	0.708	0.765	
Smart Agenda	-0.171	0.194	0.251	0.091	0.269	0.129	0.287	0.059	0.161

Figure 6: City smartness and CO_2 emissions



The time series data from the analysis of city smartness and CO_2 emissions from 2005 to 2016 are shown in Figure 6. The first graph shows the quartile distribution of Websites and the average CO_2 emissions per capita from 2005 to 2016. It is evident that there is a reduction in CO_2 emissions irrespective from the quartile classification. In both cases, the 1st quartile experienced the greatest reduction in CO_2 emissions over the time series. Cities belonging to the 2nd and 3rd quartiles for IP and Web have experienced a less extreme reduction in emissions over the same time period. From this it is possible to derive that those with low levels of smartness in terms of websites and IP addresses per capita have experienced the greatest level of reduction in CO2 emissions over the 12 years. While, cities with high level of city smartness in terms of websites and IP addresses per capita have consistently been lower than those with lower levels of city smartness, with the 1st quartile of websites being an exception. While their year over year reduction is not as significant, the overall levels are much lower and is likely to do with the diversification of their economies and the sectors it is based on.

Figure 7: Average CO_2 emissions in Scotland

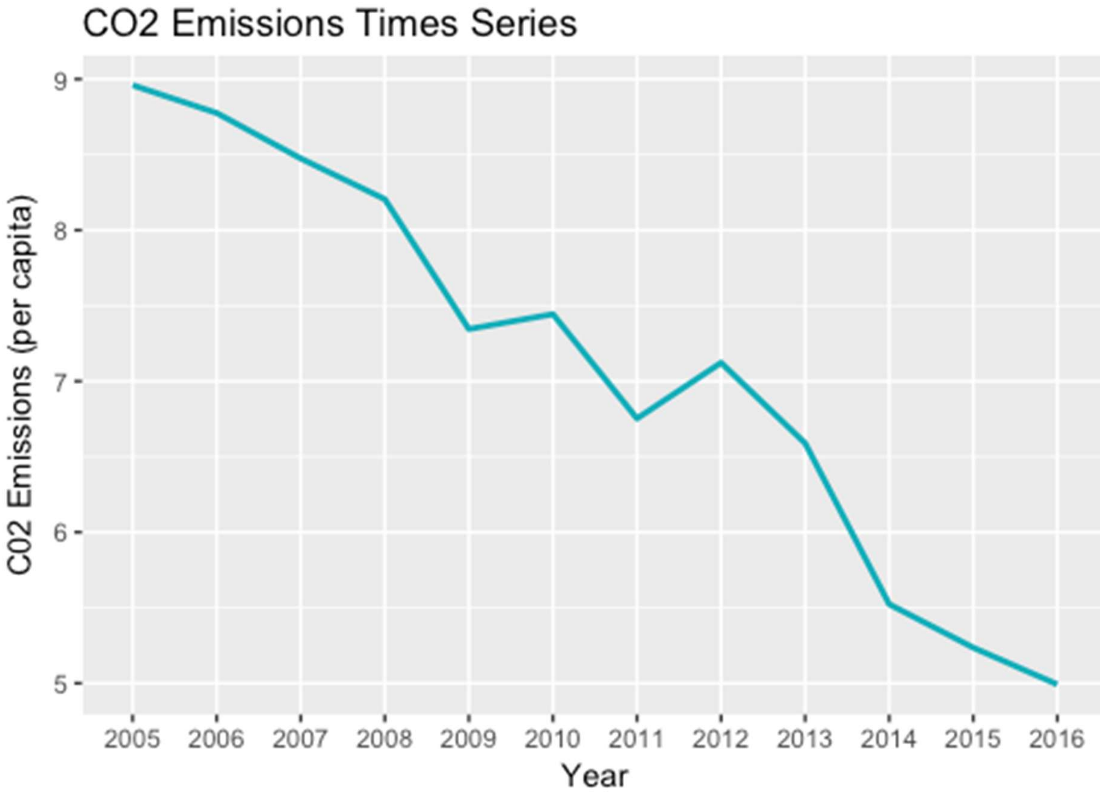
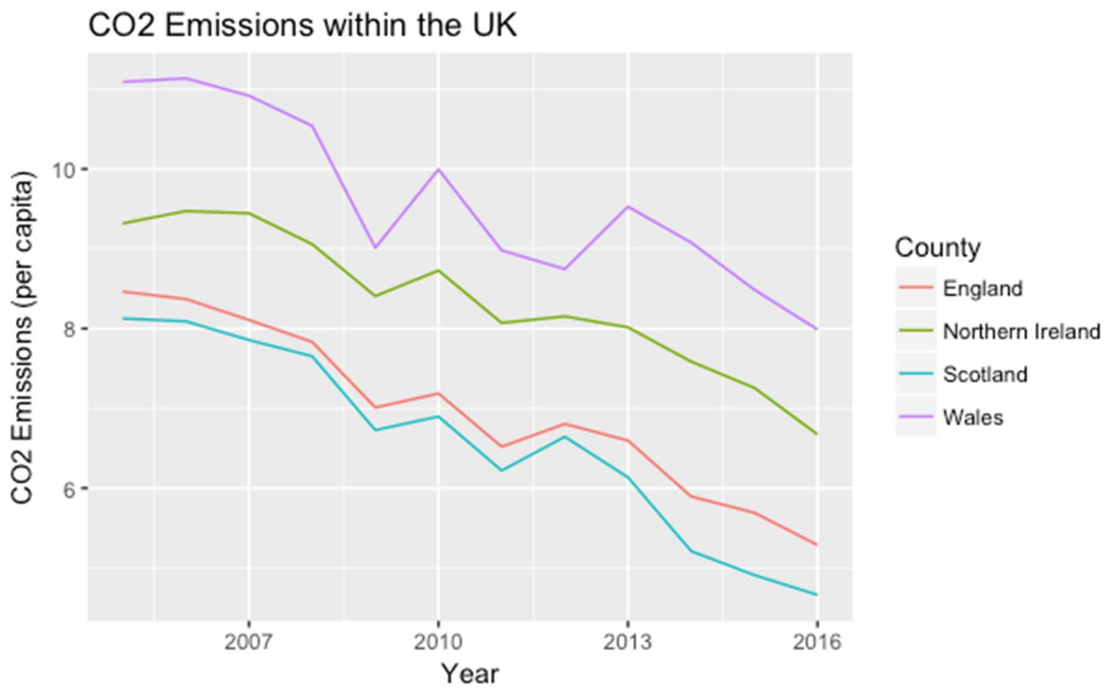


Figure 7 shows a reduction in average CO_2 emissions from 2005 to 2016 irrespective of city. This shows that overall emissions throughout Scotland have been decreasing at a relatively consistent pace.

Figure 8: Average CO_2 emissions in the UK



When comparing the emissions per capita of Scotland to those of other countries within the United Kingdom, Scotland performs quite well. In figure 8, Scotland has the lowest levels of CO_2 emissions per capita out of all countries within the United Kingdom. While these emissions can be derived from multiple sources it is important to understand both the geographical and sectoral distribution of CO_2 emissions within Scotland.

Figure 9: Average CO_2 emissions per sector

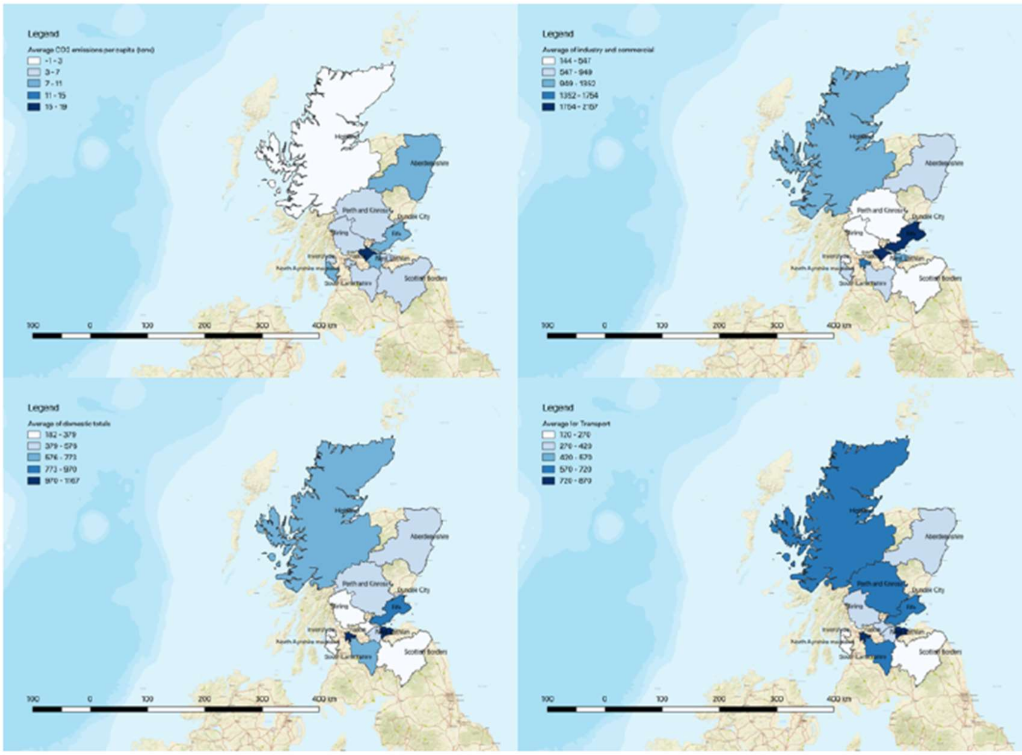


Figure 9 on the top left, shows the combined average of CO_2 emissions from 2005 to 2016 per LAD included in the study. This map shows clustering of emissions coming from per capita. Within the entire dataset there is a variance of -1 tons per capita to 19 tons per capita of CO_2 emissions. There is a clustering, albeit small of high CO_2 producing regions along the Falkirk, West Lothian and Fife regions in between Glasgow and Edinburgh. This is where the majority of the country's economic activity occurs. To place these numbers in context, the average amount of CO_2 emissions for the entire UK is 7.2 tons per capita for the same time period, 8.3 for Northern Ireland, 9.6 for Wales and 7 for England. Scotland for the same time period has experienced average CO_2 emissions of 6.6 tons per capita, which is the lowest of the United Kingdom. This is partially attributed relatively low number of large cities and density within the countries less populated areas.

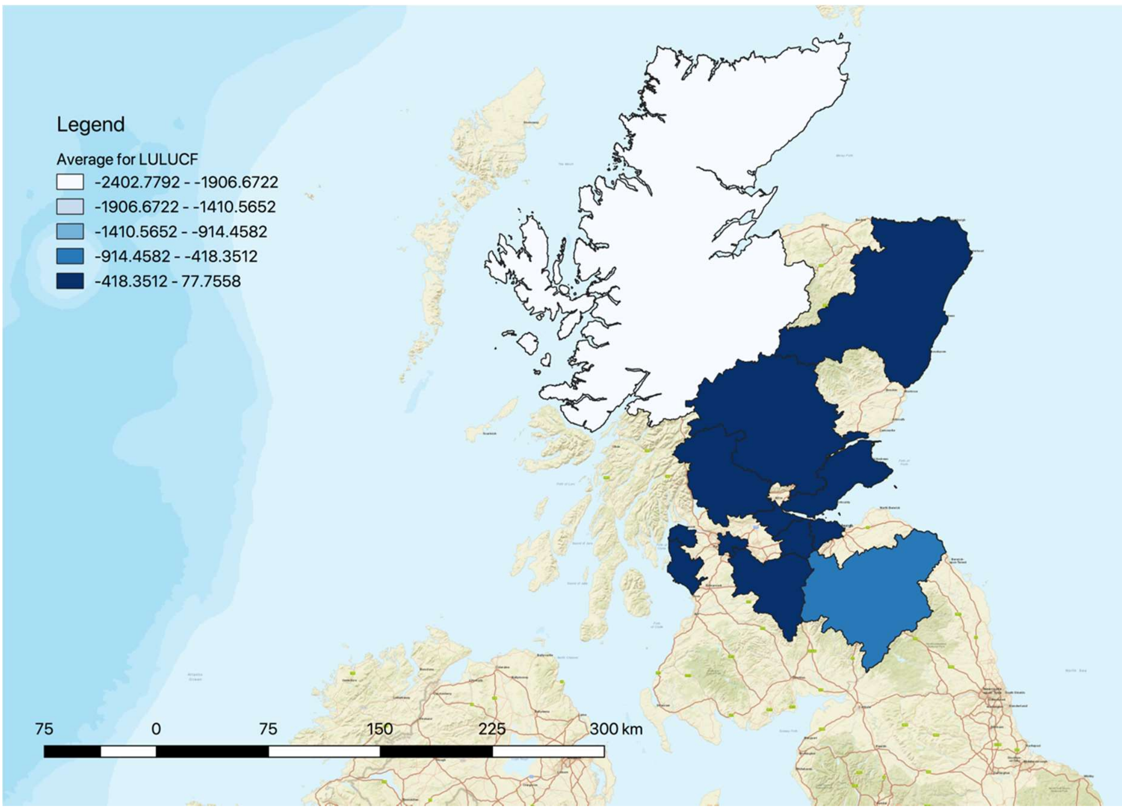
Figure 9 on the top right, shows the average CO_2 emissions specifically from Industry and Commercial Total from 2005 to 2016 per LAD included in the study. Similar to the previous map there is clear evidence of clustering between the cities of Glasgow and Edinburgh. Again, this eludes to the fact that this region in the country's main corridor of industrial and commercial manufacturing, contributing in terms of both economic activity and environmental emissions.

Figure 9 on the bottom left, shows the average CO_2 emissions specifically from Domestic use from 2005 to 2016 per LAD included in the study. Similar to the previous map we can see clustering of emissions coming from both southern and northern England as well as, the cities of Glasgow and Edinburgh in Scotland. What is unique about this map is that Leeds in central

England just north of Manchester has emerged as one of the largest domestic emitters of CO_2 emissions as well as Cornwall on the south western cape of England.

Figure 9 on the bottom right, shows the average CO_2 emissions specifically from Transportation over 2005 to 2016 per LAD included in the study. Similar to the previous map we can see clustering of emissions coming from northern England with an agglomeration of Liverpool, Manchester and Leeds and their respective suburbs. In addition to his, clustering occurs around Wiltshire in Southern England and Scotland throughout Glasgow and Edinburgh and their respective suburbs.

Figure 10: CO_2 emissions for LULUCF



Conversely figure 10 shows the net emissions from Land Use, Land-Use Change and Forestry. The United Nations is a large supporter and driver behind the use of vegetation and soils within terrestrial ecosystems as a means of reducing CO_2 emissions (UN, 1998; United Nations, 2016). The role of the LULUCF sector is to remove greenhouse gas emissions from the atmosphere by the accumulation of carbon. Forests play a large role in this as through the growth of trees forests are able to accumulate a large carbon stock.

Throughout the study there is a consistent pattern of net LULUCF emissions throughout the UK. It is evident that the majority of the region is reducing a small amount of emissions through LULUCF. The Highland LAD of Northern Scotland shows an abnormally high average of LULUCF emissions in relation to other regions. Hypothesis one states that CO_2 emissions are spatially cluster around the more industrialised cities within Scotland. The analysis shows that while it is not statistically proven, there is a strong probability that the emissions noted within the study are clustered around larger cities within Scotland. This hypothesis will next be tested through the use of a statistical spatial analysis to test the findings.

4.3 Spatial Distribution of CO_2 emissions

To further understand the spatial distribution of CO_2 emissions throughout Scotland, a spatial analysis was run. The intention of this portion of the study is to provide deeper insight into Hypothesis 1. Spatial dependence is understood as the co-variation of CO_2 emissions within Scotland. It is expected that the highest levels of emissions will be clustered in industrialized regions across the country. As shown in Fig. 9 and 10 there is a clustering of CO_2 emissions within the agglomerations of Glasgow and Edinburgh and their respective suburbs. This can be understood as the impact the clustering of the industrial sector within these regions has played a role in this. The methods utilized in this analysis are chosen based on their ability to tell us the probability that a spatial distribution of values is random. When running the Getis-Ord Gi* Statistic to reveal if there is a statistical significance in the clustering of the emissions within Scotland we see a clear group of spatial clusters surrounding Glasgow and Edinburgh and the surrounding suburbs. Figure 11 shows the Getis Ord hot spot maps with CO2 emissions on the top left showing a statistically significant cold spot in the north east of Scotland. The emissions from Industry classification is on the bottom left of the figure and shows a statistically significant hot spot of higher emission values in Glasgow. The two maps on the right had side of figure 11 show the Getis Ord hot spot maps for transport and and domestic CO_2 emissions. Both of which show statistically significant hot spots in the north east of the country meaning there is a high z-value with a corresponding low p value.

Figure 11: Getis Ord hotspot maps

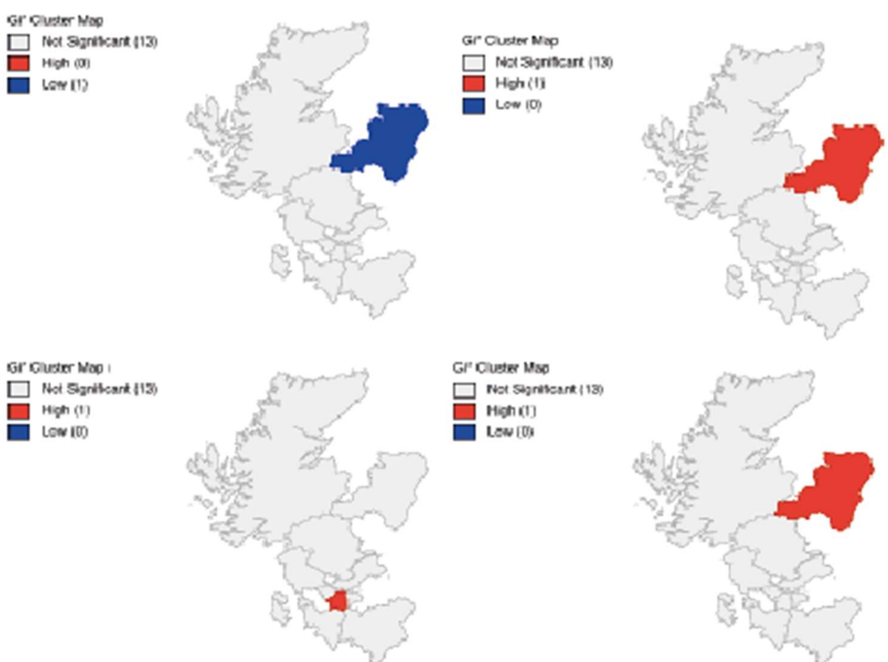


Figure 12: Getis Ord hotspot map for LULUCF

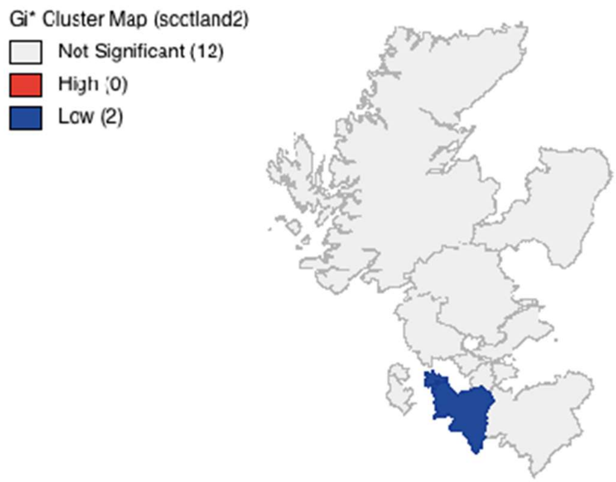


Figure 12 shows the Getis Ord hotspot map for CO_2 emissions from LULUCF. There is a statistically significant cold spot in two regions in the south west part of the country. This shows that there is a high negative z-score with a low p-value in these regions.

To statistically demonstrate that this clustering exists the Global Moran's I test was run shown in table 4 and exhibits a Moran's I index of -.01967 ($p = 0.083$). Contrary to the hypothesis that CO_2 emissions are clustered around larger cities and industrial regions as this score represents a clear dispersed pattern. When breaking down the Moran's I test into industry type we see that there is significant evidence of clustering occurring within Industry, Domestic and Transport that given the Moran's I index is much higher, closer to 1 with significant p-values. Finally, the Moran's I from LULUCF shows a more dispersed pattern as the index is 0.125 with a significant p-value.

Table 4: Moran's I

	CO2	Industry	Domestic	Transport	LULUCF
Moran's I	0.197	0.692	0.262	0.275	0.125
P -value	0.083	0.001	0.091	0.088	0.045

4.4 Inferential Analysis

Hypothesis two states that smart cities have had an impact on reducing the levels of CO_2 emissions within Scotland from 2005-2016. To test this hypothesis, a statistical investigation was conducted on Scotland to understand if smart cities have impacted emission levels. While the results are less than optimal, these models are a strong indication that a spatial component is missing from the model. As all variables within the traditional panel data model are assumed to be intendent of one another or exhibit a low level of multicollinearity.

Table 5: Results of panel regression

	Dependent variable:	
	CO_2 Emissions (per capita)	
	Fixed Effects	Random Effects
Website Quartile		1.155
		(1.924)
IP Address Quartile		1.662
		(1.836)
GVA (per capita)	-0.001^{***}	-0.001^{***}
	(0.0002)	(0.0002)
Car Traffic	-0.005	0.0001
	(0.003)	(0.002)
Inward Value	0.0003	0.0003
	(0.001)	(0.001)
Inward Count	-0.043	-0.033
	(0.035)	(0.035)
Outward Value	0.0003	0.0001
	(0.001)	(0.001)
Outward Count	0.016	0.016
	(0.036)	(0.036)
Smart Agenda	-0.396	-0.661
	(0.448)	(0.444)
Constant		6.029^{**}
		(2.817)
Observations	168	168
R^2	0.311	0.270
Adjusted R^2	0.217	0.228
F Statistic	9.479^{***} (df = 7; 147)	6.483^{***} (df = 9; 158)
Note:		$^{*}p^{**}p^{***}p<0.01$

The regression results in table 5 are the fixed and random effects of the panel data regressions without a spatial component included. Within the gross value added per capita we see a reduction of in CO_2 emissions at the 5% significance level. While this is not the direction the hypothesis had assumed, we can see a slight correlation between infrastructure and CO_2

emissions. Transportation and connectivity show insignificant results as only having more FDI come into your city shows a very slight reduction in emission levels. Most notably is the presence of smart governance and their impact on emissions. Across all regressions, the presence of a smart agenda reduced CO_2 emissions. While the amounts are quite small, it helps with the hypothesis that the presence of infrastructure, transportation, connectivity and smart governance will have an impact in reducing GHG emissions in the city.

Table 6 displays the panel data regressions with the spatial autocorrelation component included. The regressions included are the fixed and random models with a spatial lag on the dependent variable, fixed and random with a lag on the error term and a combination of the two.

Table 6: Spatial regression results

	Dependent variable:					
	CO_2 Emissions (per capita)					
	Fixed Effects Spatial Lag	Random Effects Spatial Lag	Fixed Effects Spatial Error	Random Effects Spatial Error	Fixed Effects SARAR	Random Effects SARAR
Website Quartile	0.5184	0.8874	0.6796	0.6708	0.1765	0.5551
	(0.2302)	(3.0233e-01)	(-0.2691)	(8.9355e-01)	(0.2858)	(1.1903e+00)
IP Address Quartile	0.7577	0.3478	0.2432	0.7758	0.5327	0.7910
	(0.1218)	(1.9058e+00)	(-0.73605543)	(5.6916e-01)	(0.1647)	(-5.0766e-01)
GVA (per capita)	0.0004 ***	0.0411 *	0.1878	0.3791	1.083e-06 ***	0.8806
	(-0.0005)	(-2.5517e-04)	(-0.00025293)	(-1.1370e-04)	(-0.0005)	(-1.4946e-05)
Car Traffic	0.0771	0.0390 *	0.0903	0.0097 **	0.0147 *	0.0026**
	(0.0011)	(-3.0887e-03)	(0.0014)	(-4.0662e-03)	(0.0009)	(-3.9264e-03)
Inward Value	0.0046 ***	0.2444	0.0435 *	0.0846	0.0554	0.0970
	(-0.0005)	(5.6193e-04)	(-0.0025)	(7.4198e-04)	(-0.0022)	(5.3740e-04)
Inward Count	4.409e-15 ***	0.0613	5.479e-09 ***	0.0187 *	7.540e-14 ***	0.0183 *
	(0.3710)	(-4.1129e-02)	(0.2803)	(-4.4753e-02)	(0.3200)	(-3.3532e-02)
Outward Value	0.0785	0.9594	0.0607	0.8687	0.3059	0.7026
	(0.0027)	(2.8639e-05)	(0.0027)	(-8.0263e-05)	(0.0012)	(-1.3756e-04)
Outward Count	0.2638	0.5576	0.08529	0.4236	0.5606	0.4033
	(-0.0637)	(1.3279e-02)	(-0.0980)	(1.5666e-02)	(-0.0221)	(1.2220e-02)
Smart Agenda	0.0007 ***	0.2323	0.01079 *	0.0006 ***	0.0001 ***	0.0003 ***
	(-2.5959)	(3.3511e-01)	(-1.9302)	(8.9877e-01)	(-2.3748)	(6.9172e-01)
Spatial autoregressive coefficient	2.2e-16 ***	2.2e-16 ***	2.2e-16 ***	2e-16 ***	2e-16 ***	8.683e-08***
	(0.5259)	(0.6424)	(0.6166)	(0.7270)	(0.7093)	(-0.4971)
Observations	168	168	168	168	168	168
R^2	0.6401	-1.4030	0.1486	-0.3634	0.6527	-0.9545
		24.1166		23.09195		21.0006
Sigma²	6.4884	0.6709	6.4543	0.5994	4.5171	0.3552
		23.4456		22.4925		20.6453
Log Likelihood	-408.0982	-267.732	-267.732	-264.5849	-	257.0208
Note:	*p**p***p<0.01					

In relation to the traditional panel data models, adding the spatial autocorrelation component has improved the models immensely. Thus, it is evident that by assuming cities are correlated with one another and that multicollinearity exists in a spatial and temporal aspect, more conclusive results are found. The goodness of fit in the spatial regression fixed effects spatial lag and SARAR is strong in relation to the standard panel regressions.

The models were found to be statistically significant for GVA per capita, Inward Count and the presence of a Smart Agenda all showing significant p-values across fixed, spatially lagged dependent, spatial error models and the SARAR models. The corresponding coefficients for these models show negative results of -2.60 for the fixed effects spatial lag, - 1.93 for the spatial error and -2.37 for the fixed effects SARAR models. These are all significant results with relatively high coefficients. For a city to adopt and implement a smart agenda shows that this will contribute to a reduction in CO_2 emissions on average 2.3 tons per capita across the models. As shown earlier, Scotland with the average of 6.6 tons per capita for the same time period this is very significant as approximately a third of emissions can be reduced within the city.

From this analysis it is fair to reject the null hypothesis to assume that smart cities have had an impact on reducing CO_2 emissions in Scottish cities from 2005-2016. The regressions show that spatial autocorrelation coefficient is statistically significant and that the introduction of smart city planning techniques have helped to reduce CO_2 emissions in Scottish cities.

In this research, the Hausman test was performed to select the appropriate model between the fixed effects and random effects models. Both the spatial variation and non-spatial variations of the test were performed to assess the differences in models. The results indicated that the random effects model is better than the fixed model (chisq = 8.912, p-value = 0.259). However, given the requirements to answer the research question it is imperative to analyze the effects of time invariant variables on CO_2 emissions. As a result of these constraints all models were shown for comparative purposes.

In addition, the spatial Hausman test was run to determine which effect fits the data better for each variation of the three spatial models included. For the spatial lag on the dependent variable the results indicated that the fixed effect model was preferred (chisq = 82.651, p-value = 4.79e-14). For the spatial lag on the error term the results indicated that the fixed effects model was preferred (chisq = 67.02, p-value = 5.83e-11). For the combined SARAR model the results indicated that the fixed effects model was preferred (chisq = 26.202, p-value = 0.001893). This test is used to identify if the unique errors are correlated with the regressors, in this case there is no correlation between the unique errors and the regressor.

Chapter 5: Conclusion

Over the past decade, the smart cities concept has become a widely researched topic and a priority policy agenda for many cities throughout the world. The findings revealed in this study that while there is no clear spatial pattern of emissions throughout the United Kingdom, there is still a group of cities consistently emitting at the top of the list. While smart cities are thought to be a catalyst to improving the sustainability of cities, this research has proved that while the presence of smart city planning has a significant impact on the sustainability of cities, the fundamentals of the smart city need revision from governments, academia and business. A further collaborated effort in uncovering the true impacts that smart cities have on the environmental performance of cities between all three stakeholders would improve the efficiency of smart cities.

5.1 Main Findings & Practical Implications

As previously mentioned, this study considered city smartness in terms of smart infrastructure, smart transport, connectivity and smart governance. In all cases the highest-ranking cities are the two largest, Glasgow and Edenborough. While all indicators included in the study are vital to smart cities, smart infrastructure and smart governance depict the more tangible aspects of a smart city, while the remaining indicators depict the more theoretical aspects of smart cities. In regard to smart infrastructure and governance, the two largest cities, Edenborough and Glasgow consistently rank in the highest quartile for websites and IP addresses with both possessing smart city agendas. As shown in table 3 there is a weak negative linear correlation between the model's variables and CO_2 emissions. In addition, this study has found that CO_2 emissions are spatially clustered amongst cities within Scotland and that smart cities have impacted emissions in cities over the time period. Both null hypotheses can be rejected on the grounds that spatial clustering was found within Scottish cities and that the introduction of smart agendas, acting as a proxy for smart city planning exhibits a strong reduction in CO_2 emissions. These findings have not only confirmed that there is a clustering of CO_2 emissions, amongst Scotland's largest cities, but that the introduction of smart city planning techniques has helped to reduce CO_2 emissions over this time. In answering sub question 1 and 2, this study has found that emissions are spatially clustered along corridors where the smartest cities exist. At a first glance, this is inherently counterintuitive to the real intention of smart cities. As a city becomes smarter, it will experience increase in the levels of smart infrastructure, smart transport, connectivity and smart governance. These increases will in turn contribute to increases in CO_2 emissions. As the city becomes more globally connected, more goods and services pass through the city through global and local trade, more businesses are stationed in the city, more advanced infrastructure is embedded within the city and more CO_2 emissions are produced as a result of these transformation. What was originally an idealistic intention to create a modern, connected, smart city, has resulted in an increase in CO_2 emissions. While this is the hypothesis of this study was in contradiction of this hypothetical theory, the results of this study can reject the null hypothesis on both cases. This study has found that aside from Inward Count, all variables are negatively correlated with CO_2 emissions. As any given variable goes up, which in turn implies that city smartness increases, CO_2 emissions should reduce. The issue lies his leads to a more complicated conclusion than simply identifying that based the statistical and spatial analysis run. While the results from this study answers the main research question positively, as smart city planning techniques have shown to play a role in reducing CO_2 emissions from 2005-2016 in Scotland, the total picture must be addressed. Further work would include understanding the origins of anthropogenic emissions in cities and identify if smart city indicators help to reduce these emissions. In addition to this, more concrete evaluations would be interesting to explore. As certain elements of city planning are identified to objectively reduce emissions by an amount it would be important to understand how smart city planning can play a role in this.

These findings have a high level of significance for both policy makers and businesses working within smart cities and technology. Governments around the world can draw on this study as empirical evidence that smart cities can play a role in achieving sustainable goals. While the specifics behind the smart agenda's very from city to city, it is important to note that context plays a large role in the practical implications of this study. Sustainable city planning techniques should vary from city to city and no one size fits all method should be applied. While this study merely takes the stance that adopting these general planning frameworks can assist in reducing emissions and achieving sustainability goals. Empirical evidence has shown that this specific introduction of smart city planning has worked for most of Scotland's cities, but this might not work the same way for Nairobi, Toronto or Tokyo.

Both the spatial and statistical analysis assist in answering the main research question and the three sub questions. To understand if implementing smart city planning techniques will have an impact on CO_2 emissions in Scotland, it is first crucial to understand the spatial distribution of emissions and the distribution of city smartness. Utilizing spatial analysis techniques, including Global Moran's I and the Getis Ord G statistic, it is evident that CO_2 emissions are clustered around industrial centres in the main cities within Scotland. While more remote areas

5.2 Limitations and future research

Recently, machine learning is a concept that has taken over the world by storm. It is a unique concept in which automates analytical model building to draw generalizations on empirical topics or to automate certain steps and functions. In the future, it is evident that these types of models will play a large role in helping to uncover and explain empirical topics such as this. In addition to this, these methods can help in creating new products for both software and hardware that can help to increase sustainability. Further research should include the utilization of machine learning models to understand if cities are achieving their sustainability goals, or to predict what methods of city planning are best suited for a specific context. This would help to reduce the time spent in decision making and provide valuable insight into the context of the city. Further research should include the use of supervised, semi-supervised and clustering models to further the research within smart city and sustainable city planning. In addition to this point, this study would not have been possible without open data from government sources. Governments around the world should encourage the use of data in policy making and opening this data allows for the entire world to look at issues and contribute to empirical research. This study could benefit from machine learning to predict the suggested impact on emissions resulting from a number of parameters that similar cases have experienced. The limitations to this type of study is a defined typology of a smart city and the data available.

5.3 Conclusions

In conclusion, this paper has generated new insight into smart cities through empirical evidence on whether or not smart city planning leads to the sustainability of cities. In the case of Scotland, we can see a link between smart city planning and a reduction in CO_2 emissions, but this should not be taken as an over encompassing view. Sustainable cities are very complex, and this study has not covered all aspects of this concept. Sustainable urban development includes a wide variety of inputs, including economic, social, environmental and governmental, that in conjuncture can increase city sustainability. While this is a strong building block that governments can utilise to help push policy towards smart city planning techniques, more insight is still required to help reduce anthropogenic CO_2 emissions globally.

Bibliography

Aelenei, L. *et al.* (2016) 'Smart City: A Systematic Approach towards a Sustainable Urban Transformation', *Energy Procedia*. The Author(s), 91, pp. 970–979. doi: 10.1016/j.egypro.2016.06.264.

Aguiar, F. C. *et al.* (2018) 'Adaptation to climate change at local level in Europe: An overview', *Environmental Science and Policy*. Elsevier, 86(September 2017), pp. 38–63. doi: 10.1016/j.envsci.2018.04.010.

Alizadeh, T. (2017) 'An investigation of IBM's Smarter Cites Challenge: What do participating cities want?', *Cities*. Elsevier Ltd, 63, pp. 70–80. doi: 10.1016/j.cities.2016.12.009.

Angelidou, M. (2015) 'Smart cities: A conjuncture of four forces', *Cities*. Elsevier Ltd, 47, pp. 95–106. doi: 10.1016/j.cities.2015.05.004.

Angelidou, M. (2017) 'The Role of Smart City Characteristics in the Plans of Fifteen Cities', *Journal of Urban Technology*, 24(4), pp. 3–28. doi: 10.1080/10630732.2017.1348880.

Anthopoulos, L., Janssen, M. and Weerakkody, V. (2016) 'A Unified Smart City Model (USCM) for Smart City Conceptualization and Benchmarking', *International Journal of Electronic Government Research*, 12(2), pp. 77–93. doi: 10.4018/IJEGR.2016040105.
Arup (2010) 'Smart cities', *Cities*.

Batty, M. *et al.* (2012) 'Smart cities of the future', *European Physical Journal: Special Topics*. doi: 10.1140/epjst/e2012-01703-3.

Bibri, S. E. and Krogstie, J. (2017) 'Smart sustainable cities of the future: An extensive interdisciplinary literature review', *Sustainable Cities and Society*. doi: 10.1016/j.scs.2017.02.016.

Caragliu, A., del Bo, C. and Nijkamp, P. (2011) 'Smart cities in Europe', *Journal of Urban Technology*. doi: 10.1080/10630732.2011.601117.

Chourabi, H. *et al.* (2012) 'Understanding smart cities: An integrative framework', in *Proceedings of the Annual Hawaii International Conference on System Sciences*, pp. 2289–2297. doi: 10.1109/HICSS.2012.615.

Department for Busienss Energy and Industry Strategy, U. G. (2014) 'Climate Change Explained', *Climate Change Explained*. Available at: https://www.gov.uk/guidance/climate-change-agreements--2.

Department for Business Innovation & Skills (2013) 'SMART CITIES: Background paper', *BIS Research, UK*, (October), p. 47.

Elhorst, J. P. (2014) *Spatial Econometrics From Cross-Sectional Data to Spatial Panels*. doi: 10.1007/978-3-642-40340-8.

Elhorst, J. P. (2017) ‘Spatial Panel Data Analysis’, pp. 2050–2058. Available at: https://spatial-panels.com/wp-content/uploads/2017/07/Elhorst-Spatial-Panel-Data-Analysis-Encyclopedia-GIS-2nd-ed_Working-Paper-Version.pdf.

Getis, A. and Ord, J. K. (1992) ‘The Analysis of Spatial Association by Use of Distance Statistics’, *Geographical Analysis*, 24(3), pp. 189–206. doi: 10.1111/j.1538-4632.1992.tb00261.x.

Getis, A. and Ord, J. K. (2001) ‘Testing for local spatial autocorrelation in the presence of global autocorrelation’, *Journal of Regional Science*, 41(3), pp. 411–432. doi: 10.1111/0022-4146.00224.

Giffinger, R. (2007) ‘Smart cities Ranking of European medium-sized cities’, *October*, 16(October), pp. 13–18. doi: 10.1016/S0264-2751(98)00050-X.

Hall, P. (1988) *Cities of Tomorrow: An Intellectual History of Urban Planning and Design in the Twentieth CEntury*. 2nd edn. London, UK: Blackwell Publishing.

Heinonen, J. and Junnila, S. (2011) ‘A carbon consumption comparison of rural and urban lifestyles’, *Sustainability*, 3(8), pp. 1234–1249. doi: 10.3390/su3081234.

Hill, R. C., Griffiths, W. E. and Lim, G. C. (2008) *Principles of Econometrics*. Danvers, MA: John Wiley & Sons.

Hollands, R. G. (2008) ‘Will the real smart city please stand up? Intelligent, progressive or entrepreneurial?’, *City*. doi: 10.1080/13604810802479126.

Huawei and Navigant Consulting (2016) ‘UK Smart Cities Index’, (May).

Kapoor, M., Kelejian, H. H. and Prucha, I. R. (2007) ‘Panel data models with spatially correlated error components’, *Journal of Econometrics*, 140(1), pp. 97–130. doi: 10.1016/j.jeconom.2006.09.004.

Kennedy, C. *et al.* (2009) ‘Greenhouse gas emissions from global cities.’, *Environmental science & technology*, 43(19), pp. 7297–302. doi: 10.1021/es900213p.

Kramers, A. *et al.* (2014) ‘Smart sustainable cities - Exploring ICT solutions for reduced energy use in cities’, *Environmental Modelling and Software*. doi: 10.1016/j.envsoft.2013.12.019.

Millo, G. (2012) ‘splm : Spatial Panel data models in R’, *Journal of Statistical Software*, 47(1), pp. 1–38.

Minx, J. *et al.* (2013) ‘Carbon footprints of cities and other human settlements in the UK’, *Environmental Research Letters*, 8(3). doi: 10.1088/1748-9326/8/3/035039.
OECD (2010) *Cities and climate change*, *Cities and Climate Change*. doi: 10.1787/9789264091375-en.

OECD (2017) *Green Growth Indicators 2017*. 1st edn. doi: 10.1787/9789264268586-en.
Opsahl, T., Agneessens, F. and Skvoretz, J. (2010) 'Node centrality in weighted networks: Generalizing degree and shortest paths', *Social Networks*. Elsevier B.V., 32(3), pp. 245–251. doi: 10.1016/j.socnet.2010.03.006.

Pachauri, R. K. *et al.* (2014) *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*, *Proceedings of the National Academy of Sciences*. Geneva: IPCC. doi: 10.1073/pnas.1116437108.

Parliament of the United Kingdom (2008) 'Climate Change Act 2008', *HM Government*, pp. 1–103. doi: 10.1136/bmj.39469.569815.47.

Revi, A. *et al.* (2014) 'Urban areas', *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 535–612. doi: 10.1017/CBO9781107415379.013.

Shmelev, S. E. and Shmeleva, I. A. (2009) 'Sustainable cities: problems of integrated interdisciplinary research', *International Journal of Sustainable Development*, 12(1), p. 4. doi: 10.1504/IJSD.2009.027526.

Smart London Board (2013) 'Smart London Plan: Using the creative power of new technologies to serve London and improve Londoners' lives', p. 54.

Thames, B. K. *et al.* (2018) 'UK : Local authority districts , counties and unitary authorities , 1 2017 e', p. 2018.

UN (1998) 'Kyoto Protocol To the United Nations Framework Kyoto Protocol To the United Nations Framework', *Review of European Community and International Environmental Law*, 7, pp. 214–217. doi: 10.1111/1467-9388.00150.

UN Development Programme (2016) 'UNDP Policy and Programme Brief: UNDP Support to the Implementation of the 2030 Agenda for Sustainable Development', (January), p. 30. Available at: http://www.undp.org/content/dam/undp/library/SDGs/SDG Implementation and UNDP_Policy_and_Programme_Brief.pdf.

United Nations (1992) 'United Nations Framework Convention on Climate Change', *Fccc/Informal/84*, 1(3), pp. 270–277. doi: 10.1111/j.1467-9388.1992.tb00046.x.
United Nations (2016) *World Cities Report 2016*. United Nations. doi: 10.18356/d201a997-en.

Urban Foresight (2016) 'Smart Cities Scotland Blueprint', (July). Available at: http://www.scottishcities.org.uk/site/assets/files/1103/final_-_smart_cities_scotland_blueprint_-_05-08-16.pdf.

Wall, R. S. and Stavropoulos, S. (2016) 'Smart cities within world city networks', *Applied Economics Letters*, 23(12), pp. 875–879. doi: 10.1080/13504851.2015.1117038.

Wang, S. *et al.* (2017) 'Examining the impacts of socioeconomic factors, urban form, and transportation networks on CO2emissions in China's megacities', *Applied Energy*. Elsevier Ltd, 185, pp. 189–200. doi: 10.1016/j.apenergy.2016.10.052.

WBG (2016) 'World Bank Group Climate Change Action plan 2016-2020', *World Bank Group*, p. 74. doi: 10.1111/1467-8322.12302.

Yang, W., Li, T. and Cao, X. (2015) 'Examining the impacts of socio-economic factors, urban form and transportation development on CO 2 emissions from transportation in China: A panel data analysis of China's provinces', *Habitat International*, 49, pp. 212–220. doi: 10.1016/j.habitatint.2015.05.030.

Yigitcanlar, T. and Kamruzzaman, M. (2018) 'Does smart city policy lead to sustainability of cities?', *Land Use Policy*. doi: 10.1016/j.landusepol.2018.01.034.

Zhao, X., Burnett, J. W. and Fletcher, J. J. (2014) 'Spatial analysis of China province-level CO2emission intensity', *Renewable and Sustainable Energy Reviews*. Elsevier, 33(2014), pp. 1–10. doi: 10.1016/j.rser.2014.01.060.

Zhou, C. and Wang, S. (2018) 'Examining the determinants and the spatial nexus of city-level CO2emissions in China: A dynamic spatial panel analysis of China's cities', *Journal of Cleaner Production*. Elsevier Ltd, 171, pp. 917–926. doi: 10.1016/j.jclepro.2017.10.096.

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